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Lodging In Oats and Wheat

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LODGING IN OATS AND WHEAT

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INTRODUCTION

Lodging in small grains is not a problem on poor soil. It is restricted largely to soils in a high state of fertility; that is, soils that will produce 75 to 100, or more, bushels of corn per acre. On such soils the small grains usually included in rotations with gross feeding crops like corn, potatoes, and clover develop weak stems and fall down. To maintain the high yields of the gross feeding crops, and, at the same time, avoid trouble from lodging in the small grains is a problem of growing interest on many farms.

Aside from the difficulty and nuisance attending the harvesting of tangled grain, lodging may affect both the quantity and quality of the crop, the degree of the loss varying with the completeness of the falling, the state of development at which it occurs, and the subsequent weather conditions. If lodging takes place at an early stage the loss is greatest, for it then results in the development of shrivelled, shrunken kernels of light weight. In the case of wheat, this affects adversely the quality of flour as illustrated in Figure 1.

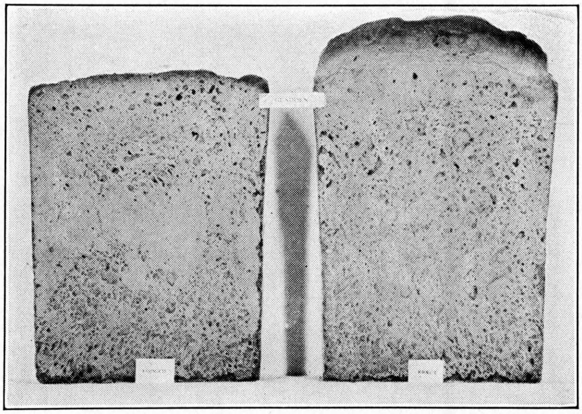

Fig. 1.—Loaves of bread made from equal quantities of flour; one lot (left) from lodged, the other from erect, wheat

HISTORICAL

The literature relating to lodging may, in a general way, be divided into three groups: observational, anatomical, and chemical.

Observational.—Thaër (49), an English physician and agriculturalist, was among the earliest to take note of lodging in wheat; he attributed it to rich ground, abundant manuring, poor plowing, thick sowing, and sometimes to a diseased condition. Kuhn (24), Mayer (30), Von Seelhorst (45), Houtman (14), Hall (12), and many others have observed that lodging is often associated with the presence of excessive nitrates or with rich ground in general. The various constituents contained in fertilizers have also been considered. Thorne and Hickman (50), for example, observed more lodging in wheat from the use of a mixture of phosphate and nitrate of soda than from the use of either alone. Murray (33) observed less lodging in rye where the fertilizers contained some potash. Harcourt (13) attributed the difference observed in a field of oats to the presence of more lime and less nitrogen in that part of the field remaining erect. In an experiment with oats in Scotland (3) a topdressing of nitrate of soda increased lodging, and common salt appeared to be more efficient than did potash as a preventive.

Anatomical.—Lienau (27), Vageler (52), Albrecht (2), Moldenhawer (32), Garber and Olson (7), Purvis (39), and others have studied lodging in relation to the anatomical structure of the plants. Most of these workers failed to find any relationship between the anatomical structure and lodging. Garber and Olson (7), however, concluded that thinness of cell walls seemed to be associated with lodging.

Chemical.—Weakness of straw has been attributed to lack of various elements, particularly silicon and potassium. That lack of silicon is responsible for lodging was first suggested by Sir Humphry Davy (5). As early as 1789, Davy discovered flint in the epidermis of rattan. He concluded that silicious earth is common in the epidermis of hollow plants and that it serves as a support.

Liebig (26) also believed that weakness of culms was due to lack of an abundance of silicon; he ascribed the strength of all stems of the grass type to silicate of potash. The importance of silicon was emphasized also by Kuhn (24), Swiecicki (48), and Kohl (21). As a result of the work of Sachs (44), Knop (19), Jodin (15), Pierre (37), Mayer (29), and others, the importance of silicon began to be questioned. As late as 1916, however, Douglas (6) gave lack of silicic acid as one of many causes for lodging in sugar cane. Perhaps its presence renders the cell walls more resistant to attacks of insect pests and fungous diseases, for Julien and Dupont (16) reported a case in which lodging of wheat was thought to be due to an infestation of two fungous diseases.

Straw weakness has also been attributed to lack of lignification in the supporting tissues in the culms. Sachs (44) observed that such a situation usually develops where the stand of plants is too thick and the culms therefore shade each other unduly and become etiolated. Lack of sufficient light was considered an important factor by Koch (20), Kraus (22), Rivera (41), Wiessman (55), Percival (36), Palladin (35), and others.

From the foregoing review, it is clear that lodging has long been associated with hypernutrition, particularly of a nitrogenous nature. It is also apparent that many have thought it related to reduced light, but no suggestion is given as to how these two factors may interact with each other to bring about such a condition.

The importance of silica from the standpoint of straw strength seems to have fallen into disrepute because plants have been found to make apparently normal growth, even to maturity, in nutrient solutions free from silicic acid. In the development of the silicic acid theory, the fact seems to have been overlooked that much of the silica found in the grasses is contained in the leaves rather than in the culms.

OBJECT

Between erect and lodged grain no arbitrary line of demarcation can be drawn; one situation merges gradually into the other. As used in this paper, however, the term *erect* is applied to grain which at harvest time stands upright, or nearly so, Figure 2. The

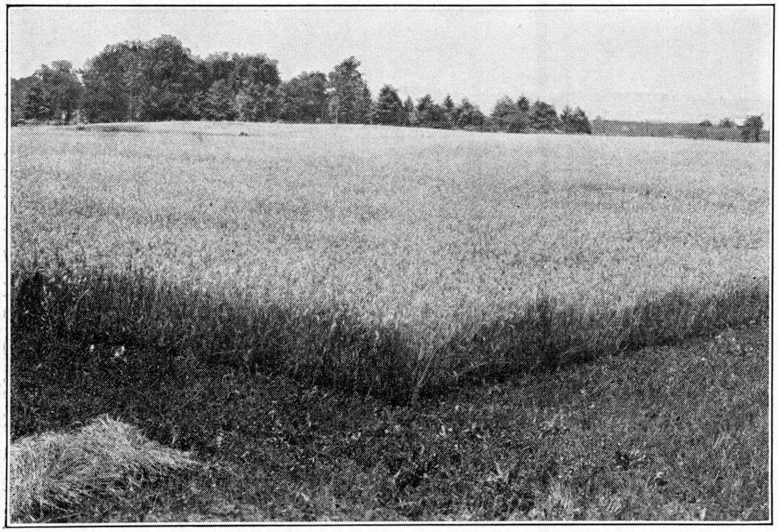

Fig. 2.—Erect grain

term *lodged* is applied to grain which has partly or completely lain over on the ground and which may have become more or less tangled. In some lodged grain the culms simply lay over without any perceptible bend at the base, as illustrated in Figure 3. In

Fig. 3.—Common type of lodging

other cases, there is an abrupt bend in the culm at one of the lower nodes, in which case a field presents an appearance like that shown in Figure 4.

Lodged grain, as here defined, may be said in a broad way to result from two sets of causes, (1) the interaction of those hereditary and environmental factors which make for the development of weak stems, and (2) external forces which exert no influence whatever on the structure of the stems, but which cause lodging through mechanical impact, such as violent wind, rain, or hail storms. This discussion is not concerned with the latter set of causes. The purpose of this paper was to ascertain the situation within the plants which results in the development of relatively soft, pliable, weak stems, on the one hand, and hard, rigid, strong stems, on the other, and to determine to what environmental factors this internal situation is responsive.

Fig. 4.—Lodging in which there is an abrupt bend in many culms

MATERIAL

Oat and wheat plants were used exclusively. Most of them were gathered from pure-line strains, although a few were taken from unselected or common varieties. Some of the material was grown in a greenhouse, but most of it was produced under field conditions. The situations in the field from which samples were selected—always in pairs, erect and lodged, unless otherwise stated—were such as years of observation and experience had shown to be favorable for non-lodging, on the one hand, and for lodging, on the other. Some of the contrasts related to conditions of growth, others to the kind of seed used. The environmental factors varied as regards fertility, light, and temperature; the seed, as regards rate of sowing, size of kernels, and varieties (some of the latter being stiff, others weak-strawed). In sampling, the culms were always cut off just above the surface of the ground.

Mechanical determinations.—To study the difference between erect and lodged plants in external as contrasted with internal characteristics, samples were gathered both at heading time and at maturity, most of them at maturity. The culms gathered at heading time were selected at random, one in a place, and usually 100 in number. The mature samples consisted chiefly of sheaves, each representing the harvest from an area one yard square. Sheaves were gathered in several successive seasons. The areas chosen in the field from which to select the two classes were no farther apart than was necessary in order to obtain grain entirely erect on the one hand and completely lodged on the other.

Chemical determinations.—To study possible internal differences between erect and lodged plants, samples for chemical analyses were gathered at heading time or soon thereafter, the stage at which lodging most frequently occurs. The samples of so-called erect culms consisted of culms standing perfectly upright and were selected in regions where all the surrounding culms were standing upright. The samples of so-called lodged culms were composed, in part, of culms selected from the border of lodged areas. Culms badly bent or otherwise distorted were avoided because it was thought that such a situation in the culms might perhaps interfere with the normal translocation of nutrients and thus set up a condition unlike that which prevailed at the time lodging was induced.

The lower third only was used, and from each culm the leaves and leaf sheathes were removed. The culms were cut into pieces one-half to one inch in length and enough weighed out to make 100-gram samples. These were placed in wide-mouthed, ground-glass-stoppered bottles and then covered with alcohol, the strength of the final solution including the moisture contained in the stems being about 70 per cent. After heating about one hour at approximately 78° C., the material was set aside and allowed to stand two months or more.

Anatomical studies.—To study the cell wall structure, a few typical green culms were selected at the same time and under the same conditions as were those used for chemical analyses. From each culm a portion was taken from the zone immediately above the lowest node. Free-hand sections were made, stained in safranin and light green, and mounted in balsam.

METHODS

MECHANICAL

To determine the proportion of straw, the sheaves were weighed and threshed, after which the grain was weighed separately and the weight of straw determined by difference. From the results thus obtained, the proportion of straw was then calculated.

To measure the relative strength of green culms, erect and lodged, the diameter, breaking strength, and solidity of a definite number, usually 100, were determined. The measurements of diameter were made on the zone immediately below a node, the fourth node below the head in oats and the third in wheat. These particular nodes were selected because many culms do not possess an additional node exclusive of the one often found just above the surface of the ground, which is frequently so contorted as to render the measurement of it impracticable. Although the zone immediately above a node is the smallest and weakest part of an internode, yet, so long as the leaf sheath remains green and clasps the culm tightly, that zone is stronger than is the one immediately below the node; hence, the latter region was measured, for it was desired to measure the point in the internode weakest at the time lodging usually occurs. The measurements were made by means of a vernier and the results recorded in millimeters and decimals thereof.

After measuring the diameter, the breaking strength of the same culm was determined. For this purpose there was removed from the culm as a whole a section 8 centimeters long, including at the center the node immediately above the zone where the diameter was measured. The breaking strength was determined by the use of a Troemner balance so adapted that the section of culm was suspended from the ends and pressure applied to the node in the middle, as the weight on the beam of the balance was increased. The reading of the scale at the time of the abrupt bending of the culm was recorded as the breaking strength. Before determining the breaking strength, each group of sections as a whole was weighed in grams, thus giving the solidity.

CHEMICAL

Extraction of the samples.—The samples were transferred to a large Soxhlet extractor with approximately 800 cc. of 80% alcohol and extracted for 8 hours. The extract, after cooling, was rinsed into a 1-liter flask, made up to volume, and passed through a dry, folded filter in order to remove any sand or dust that might have adhered to the sample.

Total nitrogen.—In the alcohol extract the total nitrogen was determined by placing 100 cc. of the extract in a Kjeldahl flask, evaporating the alcohol, and then proceeding as directed in the official method for determining total nitrogen including nitrates.

In the dry residue the total nitrogen was determined by a modification of the official Kjeldahl method.

Nitrate nitrogen.—The alcohol was distilled from a 200 cc. aliquot, the residue transferred to a 500 cc. flask, cleared with neutral lead acetate solution, made up to volume, and filtered. Nitrates were determined on the filtrate by the Devarda alloy reduction method.

Carbohydrates.—Fifty cubic centimeters of the alcohol extract were placed in a 100 cc. volumetric flask and the alcohol driven off on a steam bath. The cooled solutions were diluted somewhat and cleared by adding neutral lead acetate solution drop by drop until coagulation occurred. If carefully done, it was not found necessary to delead the solution. The flask was made up to volume, shaken, and filtered through a dry, folded filter. Twenty-five cubic centimeters of the clear filtrate were used for the determination of the reducing power.

Inverted sugars.—Twenty-five cubic centimeters of the clear filtrate were placed in a 100 cc. volumetric flask to which was then added 25 cc. distilled water and 5 cc. concentrated hydrochloric acid. The flask was then placed in a water bath at 70° C. for exactly 10 minutes. The flask was cooled, carefully neutralized with sodium hydroxide, made up to volume, shaken, and filtered through a dry, folded filter. Twenty-five cubic centimeters of the clear filtrate were used for the determination of the reducing power.

Easily hydrolyzable carbohydrates.—Two grams of the dry residue were placed in a 300 cc. Kjeldahl flask, to which were added 180 cc. of water and 20 cc. of a 25 per cent solution of hydrochloric acid. The flask was heated for two hours in a boiling-water bath, after which the sample was filtered through a linen disk in a Gooch crucible, and the residue washed thoroughly with hot water and finally with alcohol. The filtrate was then made up to volume in a 500 cc. flask. One hundred cubic centimeters were transferred to a 250 cc. flask, neutralized with sodium hydroxide, made up to volume, and the reducing power determined on 25 cubic centimeters.

The residue in the Gooch crucible was dried for 8 hours at 105° C. in a vacuum oven and weighed. Again it was transferred to the Kjeldahl flask, 200 cc. of a 1.25 per cent solution of sodium hydroxide were added, and it was then heated for one hour in a boiling-water bath. Again it was filtered through the Gooch, dried, and finally weighed. The loss in weight by digestion with sodium hydroxide was called cellulose, and the remaining residue was called lignin.

The weight of ash was found to be less than the error in analysis and was not therefore determined.

The reducing power of the sugar solution was determined as follows: Twenty-five cubic centimeters of the sugar solution were placed in a 100 cc. centrifuge tube to which were added 60 cc. of Fehling's solution. The tube was then heated in an electrically controlled water bath at 80° C. for 30 minutes after which it was centrifuged for 10 minutes, and then the Fehling's solution was poured off. The cuprous oxide was washed with 15-20 cc. of freshly boiled, distilled water, after which was added a little powdered talc and the mixture was again centrifuged for 10 minutes. The supernatant liquid was poured off, a glass bead added to stir up the cuprous oxide, and the amount of copper determined by the Bertrand titration method using N/20 $KMnO_4$.

General statement.—The total reducing power of the extract before hydrolysis is recorded as free-reducing sugars. The increase in the reducing power of the extract after hydrolysis represents inverted sugars.

Easily hydrolyzable carbohydrates are the substances obtained by hydrolysis of the dry residue. In all three cases the results are expressed as dextrose.

Dry weight.—The residue from extraction was air-dried over a steam plate for several days, and then placed in a vacuum oven for 4 hours at 105° C. The residue, after weighing, was ground finely in a mill and then placed in air-tight containers. In order to determine the amount of dry matter in the alcohol extract, 50 cc. of the solution were transferred to a platinum dish, placed first on a steam bath, and finally in a vacuum oven at 78° C. until constant weight was attained. The sum of the two gave the total dry weight in 100 grams of fresh sample and hence the per cent of dry matter.

RESULTS

LODGING IN RELATION TO VEGETATIVE GROWTH

Proportion of straw.—A comparison of sheaves of erect and lodged grain shows that lodging is associated with a preponderance of vegetative, as contrasted with reproductive, growth. Sheaves of erect and lodged oats were gathered from fields of mature grain in 1920, 1921, 1922, 1923, and 1924. The strain of oats, the percentage of straw in each individual sample, and the average of the ten samples of each class, erect and lodged, for each year are shown in Table 1.

TABLE 1.—Percentage of Straw in Erect and Lodged Oats

	1920 Ohio 6222		1921 Ohio 201		1922 Ohio 201		1923 Ohio 201		1924 Ohio 201	
	Erect	Lodged	Erect	Lodged	Erect	Lodged	Erect	Lodged	Erect	Lodged
	62.1	77.3	64.8	75.2	92.6	87.7	60.5	64.5	61.1	67.2
	59.0	79.6	62.9	76.4	94.4	86.5	57.0	73.8	60.6	68.0
	61.8	81.8	64.1	74.1	93.7	82.2	60.0	62.4	58.4	64.0
	63.6	85.5	65.0	74.4	90.6	90.3	59.9	68.9	59.9	65.9
	60.2	79.6	65.5	73.5	92.1	91.6	62.8	67.1	62.7	64.3
	59.1	93.2	69.8	75.1	93.4	86.9	59.3	73.1	60.6	64.3
	61.9	90.8	68.8	78.1	84.9	92.5	65.4	68.6	58.1	67.6
	60.6	95.9	68.0	75.9	70.7	76.4	60.8	71.1	56.7	62.4
	59.8	93.3	66.5	74.3	92.2	92.8	64.1	65.3	53.0	63.7
	61.4	94.4	66.4	77.6	92.3	91.8	58.9	65.4	58.4	70.2
Av.	60.9	87.1	66.2	75.4	89.7	87.9	60.9	68.0	59.0	65.8

TABLE 2.—Percentage of Straw in Erect and Lodged Wheat

	1919				1920				1921		1923		1924	
	Gladden		Fulhio		Fultz		Fulhio		Fulhio		Fulhio		Fulhio	
	Erect	Lodged	Erect	Lodged	Erect	Lodged	Erect	Lodged	Erect	Lodged	Erect	Lodged	Erect	Lodged
	71.4	80.7	69.6	73.4	52.4	76.8	61.2	73.5	69.9	79.2	66.9	73.7	56.0	67.2
	68.0	85.3	72.5	74.3	70.5	78.4	63.0	71.8	78.8	75.5	63.1	76.0	63.3	72.9
	74.6	79.3	70.3	75.3	68.7	75.2	65.3	72.2	76.1	72.4	63.1	70.3	62.9	74.0
	71.5	78.8	72.4	74.1	69.8	75.5	60.6	70.5	79.2	81.1	61.9	71.7	69.1	65.3
	71.2	83.3	71.4	74.8	70.2	74.1	61.4	72.5	70.4	72.5	61.9	70.1	70.1	75.2
	70.9	81.5	72.7	79.2	69.3	73.7	62.2	74.1	69.1	71.1	85.9	73.3	68.1	66.9
	71.7	86.9	69.5	74.7	71.2	81.1	65.5	71.8	69.1	70.3	67.8	71.9	60.8	73.8
	70.4	73.5	68.2	71.6	69.4	80.1	67.9	71.3	68.9	73.9	69.6	74.2	67.9	71.8
	71.0	74.0	69.3	73.5	70.2	78.2	65.7	71.7	68.9	69.7	....	....	76.0	72.7
	71.8	87.2	68.6	74.9	69.6	80.2	66.1	70.4	70.5	71.8	....	....	65.6	66.1
Av.	71.2	81.0	70.4	74.6	68.1	77.3	63.9	71.9	72.1	73.7	67.5	72.6	66.0	70.6

The percentage of straw was higher in the lodged oats in each of the pairs in every year except 1922. In that year a violent wind and rain storm caused most of the field to lodge and this rendered difficult an accurate separation of the erect from that which would probably have lodged under normal conditions.

Sheaves of erect and lodged wheat were gathered in 1919, 1920, 1921, 1923, and 1924. In 1919 and 1920 two series were selected. All the sheaves were gathered from pure-line strains, except one series in 1920 which was taken from a common variety—the Fultz. The name of the wheats, the percentage of straw in each individual sample, and the average of each class, erect and lodged, for each year are shown in Table 2.

The percentage of straw was higher in the lodged than in the erect wheat in 62 of the 68 single comparisons, and in every case on the basis of the averages. Considering both oats and wheat, the percentage of straw was higher in the lodged than in the erect grain in 105 of the 118 individual comparisons, or in 89 per cent of the cases.

The higher percentage of straw in the lodged than in the erect grain was due, in part, to a greater number and, in part, to a greater length of culms in the latter. The number of culms in each sheaf, represented in Tables 1 and 2, is shown in Table 3 for oats and in Table 4 for wheat.

In the 50 comparisons made with oats, 46, or 92 per cent, of them showed a greater number of culms in the lodged than in the erect sheaves. Likewise, the wheat showed a similar result in 94 per cent of the comparisons.

Lodged culms were also found to be longer than erect ones, the average length, including the heads, of 800 being 1319 mm. for the lodged and 885 mm. for the erect, a gain for the former of 434 mm., or 49 per cent. The increase in length was due chiefly to greater elongation of internodes, particularly the upper ones, but in some cases to an increase in number of internodes. The 800 culms of each class were composed of four individual samples of 200 culms each. The separate samples were selected from different parts of a wheat field which was more or less rolling and which, therefore, afforded conditions favorable both for non-lodging and lodging.

The heads produced on lodged culms were longer but lighter. The average length of 1000 panicles each of erect and lodged oat heads was found to be 255 mm. for the former and 276 mm. for the latter. The average weight of the same heads was 1890 mg. for the erect and 1700 mg. for the lodged. Similar measurements and

TABLE 3.—Number of Culms per Square Yard in Erect and Lodged Oats

	1920 Ohio 6222		1921 Ohio 201		1922 Ohio 201		1923 Ohio 201		1924 Ohio 201	
	Erect	Lodged	Erect	Lodged	Erect	Lodged	Erect	Lodged	Erect	Lodged
	266	344	214	221	163	183	216	222	226	268
	285	366	129	244	202	185	211	201	188	287
	287	322	178	218	208	240	175	220	169	243
	274	333	158	222	196	238	221	233	180	262
	263	323	157	215	224	232	213	276	175	233
	275	343	156	313	167	218	205	230	162	252
	258	316	226	179	194	228	202	234	160	286
	272	318	181	197	175	199	246	214	143	270
	315	321	187	246	204	227	228	268	137	289
	273	331	204	248	200	231	222	240	179	277
Av.	277	332	179	230	193	218	213	233	172	267

TABLE 4.—Number of Culms per Square Yard in Erect and Lodged Wheat

	1919				1920				1921		1923		1924	
	Gladden		Fulhio		Fultz		Fulhio		Fulhio		Fulhio		Fulhio	
	Erect	Lodged	Erect	Lodged	Erect	Lodged	Erect	Lodged	Erect	Lodged	Erect	Lodged	Erect	Lodged
	462	561	460	577	407	624	302	609	436	610	555	597	483	799
	473	695	390	540	406	579	282	519	445	582	558	513	595	763
	591	678	429	535	406	576	367	711	460	605	498	714	547	666
	480	560	421	667	404	592	274	473	493	617	565	493	564	545
	437	653	406	537	389	613	211	645	478	500	608	590	559	616
	476	645	380	582	394	535	282	667	454	539	463	510	444	752
	480	688	577	628	380	658	424	425	471	548	544	675	536	474
	429	554	420	477	446	631	401	490	440	484	410	779	466	669
	405	513	441	615	391	685	348	497	461	472	....	....	539	625
	393	651	482	540	460	644	370	504	447	485	....	....	492	738
Av.	462	619	440	569	408	614	326	554	458	544	525	609	523	665

weights made on 1000 spikes each of erect and lodged wheat heads gave an average of 72 and 75 mm. and 900 and 830 mg., respectively.

Tillering in relation to nitrates and moisture.—Since all the oat and wheat sheaves heretofore mentioned were grown in fields each seeded at uniform rates, it follows that the difference in stand must have been due to a greater degree of tillering in some parts than in others. The lodged grain was always found in soil depressions and ravines; the erect, on adjoining but more elevated land.

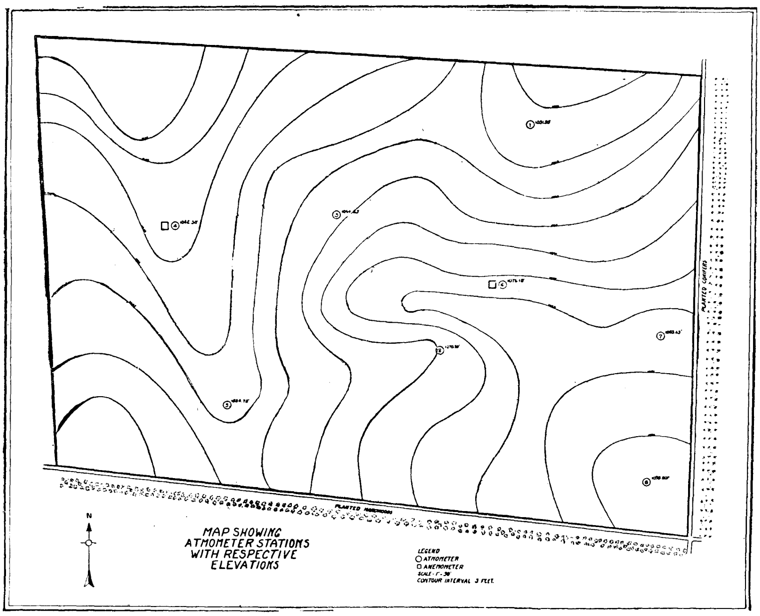

Fig. 5.—Contour map

Soil nitrates.—Relatively low land contains more potential nitrates than does adjoining but more elevated soil. In a rolling field of wheat, a contour map of which is shown in Figure 5, eight composite soil samples to a depth of seven inches were taken in 1921; four from depressions and ravines and four from more elevated points. The eight points are indicated on the map. The total nitrogen found averaged 0.137 per cent on the lower and 0.076 per cent on the higher ground. Having a greater quantity of total nitrogen in the lower than in the higher ground, it is reasonable to assume that under favorable weather conditions, a greater quantity of nitrates would be available. In fact, nitrate determinations made on a series of samples taken from these points during the months of June and July showed more nitrates in the low ground during the most favorable growing weather.

Soil moisture.—Low land contains also more moisture than does more elevated soil. In the same field and from the same eight locations a series of soil samples was taken on which moisture determinations were made. The samples were taken at intervals of 10 days or so, beginning May 26 and continuing to July 27. A summary of the results showed an average of 16.00 per cent for the four low points and 11.45 per cent for the four high ones, a difference of 4.55 per cent. Between the extremes, there was a difference of 9.37 per cent.

Moreover, the difference in moisture actually available for the use of plants on low and high ground is greater than the difference in soil moisture would indicate, for the loss through evaporation is less on the former than on the latter. At each of the eight points one of Livingston's standardized spherical white atmometers was placed May 26. With a few exceptions, daily readings were made through October 5. On rainy days the readings were discarded, for the atmometers were not equipped so as to prevent the entrance of rainwater. Not many readings, however, were lost because the summer of 1921 was unusually dry. The average corrected daily evaporation from each atmometer, month by month, expressed in cubic centimeters, is shown in Table 5.

TABLE 5.—Rate of Evaporation in Low and High Ground

Date	Low ground				High ground			
	1	2	3	4	5	6	7	8
	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.
June...............	10.35	11.45	10.30	9.30	13.10	20.60	13.60	11.40
July...............	31.60	28.80	26.50	26.10	34.75	43.45	36.00	33.30
August............	27.10	27.40	24.60	24.45	34.50	39.80	29.85	30.40
September.........	16.55	16.70	16.85	16.60	22.05	26.20	....	18.90

The average daily evaporation at the four low points was 20.3 cc. and at the four high, 27.2 cc., a difference of 6.9 cc. Between the extremes there was an average difference of 12 cubic centimeters.

The difference in rate of evaporation was due, at least in part, to a less rapid movement of air in the lower points. An anemometer was placed at the lowest point and another at the most exposed point. They were not put out every day during the summer and when they were used, the number of hours of exposure varied from one to ten. The readings were started May 26 and were continued irregularly thereafter through October 2. Most of them were taken in the months of June and September. They were exposed on 60 different days and a total of 303.4 hours. The average rate of movement of air per hour was 2.9 miles at the low point and 4.7 miles at the more exposed one, a difference of 1.8 miles or an increase of 62.1 per cent as compared with that of the higher ground. The low, therefore, not only receives more water through drainage by virtue of its location, but it loses less through evaporation, presumably on account of a more sluggish movement of the atmosphere.

Tillering on low ground.—With more nitrogen and more moisture at the low points, a greater number of culms would be expected, for both of these factors favor tillering. This property of nitrogen is so well known that it hardly needs mention here. In passing, however, reference may be made to the tillering of wheat grown in greenhouse tests, the chief object of which was to note the effect of deferred applications of nitrate of soda. In one test, the average number of culms per plant was 2.2 in the untreated and 3.0 in the treated; in the other, 2.0 and 2.7 culms per plant, respectively. In a similar test carried out in a field in rows 50 feet long, the average number of culms per row was 1831 for the untreated and 2006 for the treated, an increase of 175 culms or 9.6 per cent.

Moisture also favors lodging. Wheat grown in a greenhouse in jars, the moisture content of the soil in one set of crocks being maintained at optimum minus, in the other at optimum plus, showed an average number of culms of 7.4 for the former and 8.5 for the latter. Furthermore, the water content of the culms grown on the optimum minus soil was less than that of the culms grown on the optimum plus, there being a difference of 1.8 per cent. From the standpoint of lodging, moisture content of culms is of considerable moment as will be indicated later.

VEGETATIVE GROWTH IN RELATION TO CARBOHYDRATES

Sand-soil-manure.—A low carbohydrate content of the culms resulted from hypernutrition and this in turn was accompanied by a preponderance of vegetative or straw growth. Soils were artificially prepared so as to represent wide extremes in fertility. The poor soil consisted of one part by measure of good silt loam mixed with three parts of screened creek sand. The rich soil was made by mixing with the silt loam some well-rotted manure in the proportion of one part by measure of soil to three parts of manure. The two classes of artificial soil were prepared to a depth of seven inches—ordinary plowing depth—and each embraced an area of one square yard. They were arranged one on either side of an equal area of the natural soil—the Wooster silt loam. They were separated from each other by one-inch boards. The three classes were called sand-soil-manure, and henceforth in this paper will be so designated. Nitrate determinations made in the early summer of one season showed 2.4, 3.9, and 135 parts per million in the sand-soil-manure, respectively. Both oats and wheat were grown on these three classes of soil in 1922, 1923, and 1924.

In general, the stems produced on the manure were soft, pliable, and succulent and the leaves were dark green; while the stems grown on the soil, and especially those grown on the sand, were small and tough and the leaves light green. Furthermore, the plants grown on the manure developed more and longer culms, thus resulting in a greater percentage of straw, and in each year they lodged or showed a strong inclination to lodge, while those grown on the soil and sand stood perfectly erect. The difference in stiffness is indicated by the character of the sheaves shown in Figure 6.

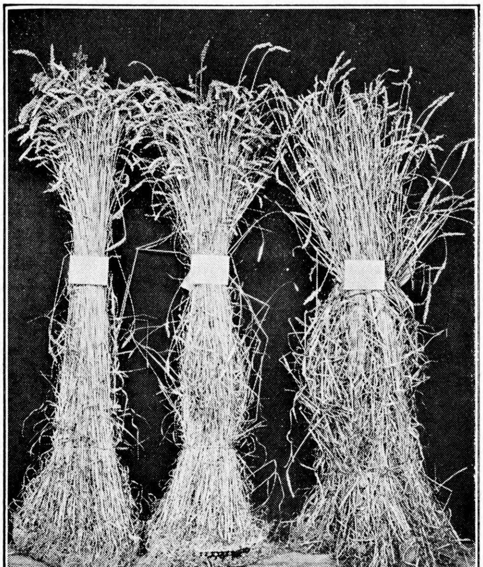

Fig. 6.—Sheaves of wheat from sand (left), soil (center), and manure (right) square-yard areas

Samples for analysis were collected each year and the results of these are shown in Table 6.

TABLE 6.—Fertility in Relation to Composition of Oat and Wheat Culms

Material	Oats			Wheat		
	¾ Sand ¼ Soil	Soil	¼ Soil ¾ Manure	¾ Sand ¼ Soil	Soil	¼ Soil ¾ Manure
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1922						
Moisture	74.0	72.6	80.7	67.7	69.9	75.0
Dry matter	26.0	27.4	19.3	32.3	30.1	25.0
Nitrate nitrogen	0.002	0.004	0.018	0.000	0.001	0.021
Total nitrogen	0.076	0.062	0.080	0.154	0.138	0.197
Free reducing sugars	2.8	2.1	1.2	1.4	1.4	0.7
Inverted sugars	0.0	0.0	0.2	3.3	2.4	1.5
Easily hydro. carbohydrates	4.6	4.9	3.0	5.6	5.3	4.2
Cellulose	4.4	4.9	3.2	4.5	4.6	4.3
Lignin	8.8	9.0	5.9	10.5	10.4	8.0
Total carbohydrates	20.6	20.9	13.5	25.3	24.1	18.7
1923						
Moisture	73.8	72.9	77.3	71.8	73.8	79.2
Dry matter	26.2	27.1	22.7	28.2	26.2	20.8
Nitrate nitrogen	0.021	0.017	0.058	0.003	0.006	0.066
Total nitrogen	0.180	0.181	0.357	0.176	0.173	0.278
Free reducing sugars	1.9	2.2	1.9	2.0	2.4	0.8
Inverted sugars	0.6	1.5	2.0	5.4	3.2	1.0
Easily hydro. carbohydrates	6.1	5.7	4.1	5.7	5.3	4.0
Cellulose	3.3	3.3	2.6	3.1	3.1	3.0
Lignin	7.3	7.7	5.9	6.8	7.1	6.0
Total carbohydrates	19.2	20.4	16.5	23.0	21.1	14.8
1924						
Moisture	76.1	77.1	80.2	59.0	69.8	79.4
Dry matter	23.9	22.9	19.8	41.0	30.2	20.6
Nitrate nitrogen	0.001	0.005	0.123	0.001	0.003	0.052
Total nitrogen	0.048	0.044	0.215	0.095	0.062	0.116
Free reducing sugars	1.7	1.8	0.5	1.9	2.1	1.0
Inverted sugars	2.9	2.0	1.7	9.6	7.9	1.1
Easily hydro. carbohydrates	4.5	4.3	3.4	9.1	5.5	3.9
Cellulose	3.1	3.3	2.7	4.7	3.0	3.2
Lignin	9.5	8.9	6.5	11.9	7.9	7.2
Total carbohydrates	21.7	20.3	14.8	37.2	26.4	16.4

In both crops and in each year the relationship between the nitrogen and total carbohydrate content of the stems grown on the manure was the reverse of what it was in the culms grown on the soil and especially on the sand; the nitrogen being high and the total carbohydrates low in the former case, and the nitrogen being low and the total carbohydrates high in the latter. The plants possessing a low carbohydrate content, that is, the ones grown on the manure, were, as has already been stated, characterized by a high proportion of vegetative or straw growth and ultimate lodging.

Shading.—A low carbohydrate content resulted from shading and this in turn was accompanied by a preponderance of vegetative growth. Frames about 12 feet square and 5 feet high were covered with a single layer of cheesecloth, ample provision being made for the free circulation of air, and these were used to cover oats and wheat growing in general fields. The frames were placed in position shortly before heading time and were allowed to remain there until harvest. This was done in four seasons—1921, 1922, 1923, and 1924.

The shaded plants grew somewhat taller than did the unshaded and thus developed a relatively high proportion of vegetative or straw growth. In two of the four seasons, there was some lodging in the general fields in which the frames were placed, but none in their immediate vicinity. In all four years, however, the shaded grain lodged; typical examples are indicated in Figures 7 and 8.

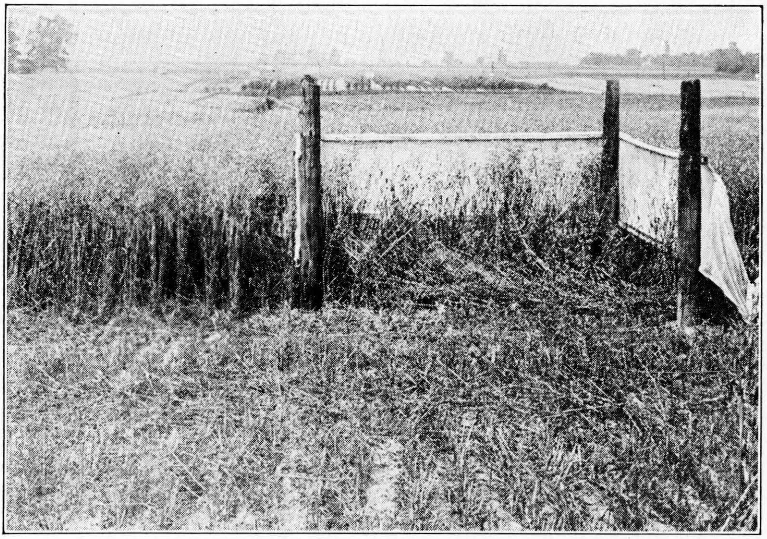

Fig. 7.—Oats shaded with cheesecloth from June 30 to July 31 (31 days)

Samples for analysis were collected in 1923 and 1924, and the results of these analyses are shown in Table 7.

In both crops and in both years the total carbohydrates were markedly reduced in the shaded as contrasted with the unshaded plants.

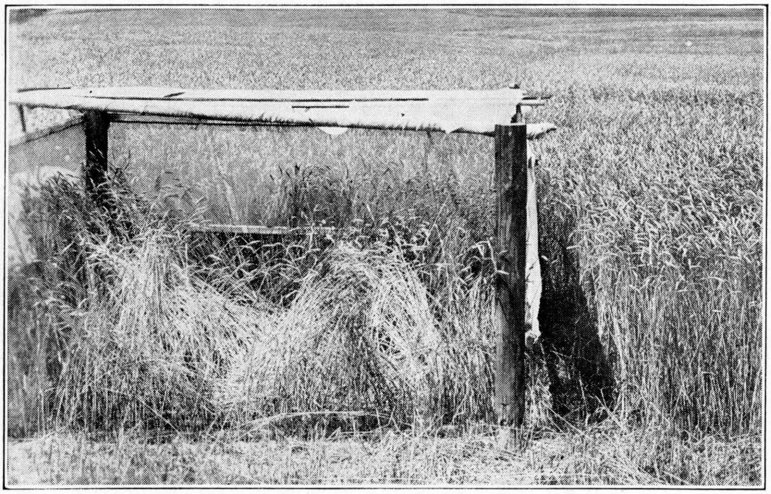

Fig. 8.—Wheat shaded with cheesecloth from May 17 to June 20 (34 days)

TABLE 7.—Shade in Relation to Composition of Oat and Wheat Culms

Material	Oats		Wheat	
	Unshaded	Shaded	Unshaded	Shaded
	Per cent	Per cent	Per cent	Per cent
1923				
Moisture	79.8	84.1	61.5	65.6
Dry matter	20.2	15.9	38.5	34.4
Total nitrogen	0.159	0.172	0.118	0.129
Free reducing sugars	2.4	1.3	1.8	2.8
Inverted sugars	0.8	0.5	9.0	0.8
Easily hydrolyzable carbohydrates	3.6	2.6	7.1	6.4
Cellulose	2.6	2.2	4.3	4.9
Lignin	6.1	5.0	11.4	10.8
Total carbohydrates	15.5	11.6	33.6	25.7
1924				
Moisture	77.2	84.7	75.8	78.9
Dry matter	22.8	15.3	24.2	21.1
Total nitrogen	0.103	0.059	0.060	0.067
Free reducing sugars	1.8	0.5	2.5	2.3
Inverted sugars	0.4	0.0	7.1	1.9
Easily hydrolyzable carbohydrates	4.3	3.0	4.5	4.0
Cellulose	3.4	2.9	2.9	3.0
Lignin	9.6	6.2	6.8	6.6
Total carbohydrates	19.5	12.6	23.8	17.8

Temperature.—A low carbohydrate content of the plants resulted from an increase in temperature and this in turn was accompanied by a preponderance of vegetative growth. Rather crude frames, appproximately 6 feet square and 6 feet high, were made from large window sash and these were used to cover an area each of oats and wheat growing in general fields. Since the quality of light is changed by passing through ordinary window glass, a second area each of oats and wheat approximately 12 feet square was covered with window glass, the sides being left open in order not to affect appreciably the temperature. These coverings were raised from time to time as the oats and wheat increased in height. It was thought that this arrangement would result in light of the same quality in both areas and that any difference, therefore, in composition of the plants grown under the two conditions might be attributed, in large measure at least, to the higher temperature in the inclosure, although it is probable there was some variation in humidity. The rate of evaporation as shown by atmometers was somewhat greater inside than outside the inclosure. No artificial heat was applied, and hence the amount of increase within was dependent entirely on the outside temperature. On warm days the maximum increase ranged from 8 to 10 degrees Fahrenheit. The temperature under the glass cover, even on the warmest days, rarely exceeded that outside by more than 1 or 2 degrees. At the time of covering, the oats were about 18 inches tall; the wheat was much smaller, approximately 4 inches high. The frames remained in position until harvest time.

The plants, both oats and wheat, grown in the inclosures were taller than those grown under the glass cover or in the open, and they developed a relatively high proportion of straw. Both crops

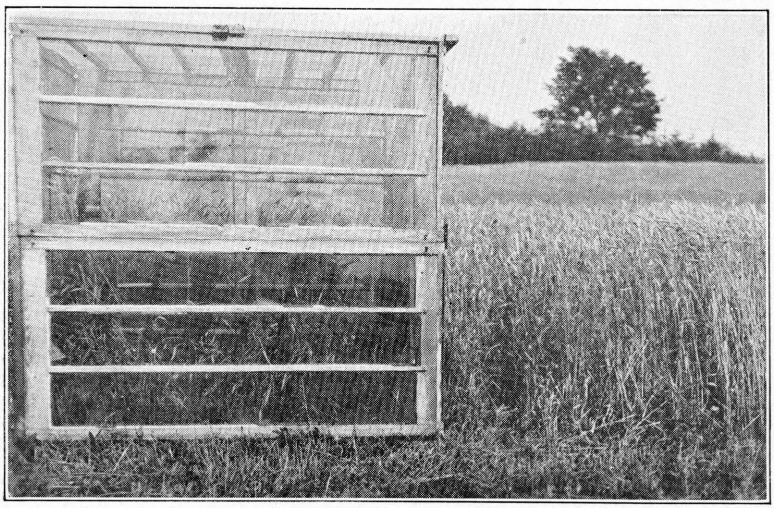

Fig. 9.—Wheat grown at different temperatures

lodged badly in the inclosures. Under the glass covers there was some indication of lodging but the plants there never lodged as badly as did those in the inclosures. In the adjacent open field of both oats and wheat, the plants stood erect. The lodged condition of the wheat in the inclosure is shown in Figure 9. A sample of oats and wheat for analysis was taken from the inclosure, from under the glass cover, and from the open. The results of the analyses are given in Table 8.

TABLE 8.—Temperature in Relation to Composition of Oat and Wheat Culms

Material	Oats			Wheat		
	Open	Protected by glass		Open	Protected by glass	
		Cover	Inclosure		Cover	Inclosure
	%	%	%	%	%	%
Moisture	77.2	79.9	82.8	68.4	73.9	78.1
Dry matter	22.8	20.1	17.2	31.6	26.1	21.9
Total nitrogen	0.103	0.114	0.097	0.051	0.065	0.059
Free reducing sugars	1.8	0.8	0.6	1.5	1.2	1.0
Inverted sugars	0.4	0.5	0.3	9.0	5.7	2.1
Easily hydrolyzable carbohydrates	4.3	3.4	3.0	6.2	4.9	4.8
Cellulose	3.4	3.4	3.2	4.3	4.3	4.2
Lignin	9.6	8.5	7.1	8.3	8.8	7.8
Total carbohydrates	19.5	16.6	14.2	29.3	24.9	19.9

The nitrogen content of the plants was not materially affected by the glass in either the oats or wheat, but the total carbohydrates were reduced somewhat by the glass cover and very markedly by the inclosure. The greater reduction in the wheat than in the oats was probably due to the fact that the former was covered at a much earlier stage of development than was the latter.

Carbohydrates in relation to dry matter per unit length of culm.—In the three tests thus far reported, it may be noted that the low carbohydrate content, whether induced by hypernutrition, shading, or high temperature, resulted always in a relatively low percentage content of dry matter. The difference in content of dry matter between erect and lodged plants becomes even more marked if the constituents are calculated to a given length per culm, and in the three following tables this has been done, for, after all, it is the composition of the individual culms rather than the mass of material as a whole which is most significant in indicating relative strength of stems. The constituents per unit length of culm were as shown in Tables 9, 10, and 11 for the sand-soil-manure, the shading, and the temperature tests, respectively.

TABLE 9.—Fertility in Relation to Constituents per Unit Length of Oat and Wheat Culms. 1924*

Material	Oats			Wheat		
	¾ Sand ¼ Soil	Soil	¼ Soil ¾ Manure	¾ Sand ¼ Soil	Soil	¼ Soil ¾ Manure
	mg.	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*
Moisture	61.3	67.1	55.7	38.4	40.8	48.8
Dry matter	19.3	19.9	13.7	26.6	17.7	12.7
Total nitrogen	0.04	0.04	0.15	0.06	0.04	0.07
Free reducing sugars	1.3	1.5	0.4	1.2	1.2	0.6
Inverted sugars	2.3	1.7	1.2	6.2	4.6	0.7
Easily hydro. carbohydrates	3.6	3.7	2.4	5.9	3.2	2.4
Cellulose	2.5	2.8	1.9	3.1	1.8	2.0
Lignin	7.7	7.8	4.5	7.7	4.6	4.4
Total carbohydrates	17.4	17.7	10.3	24.2	15.4	10.1
Number of culms per 100 gm	31	28	45	64	57	44
Average length of culms, cm	40	41	32	24	30	37
Total length of culms, cm	1240	1148	1440	1536	1710	1628

*In this and succeeding tables giving "composition per unit length of culm" the figures were obtained by dividing the percentage composition by the total length of culms in cm., the latter having been obtained in 1924 by keeping a record of the number and length of culms of which each 100-gram sample consisted. The results are expressed in mg.

TABLE 10.—Shading in Relation to Constituents per Unit Length of Oat and Wheat Culms. 1924

Material	Oats		Wheat	
	Unshaded	Shaded	Unshaded	Shaded
	mg.	*mg.*	*mg.*	*mg.*
Moisture	82.2	64.1	42.5	34.6
Dry matter	24.2	11.6	13.6	9.3
Total nitrogen	0.11	0.04	0.03	0.03
Free reducing sugars	1.9	0.4	1.4	1.0
Inverted sugars	0.0	0.0	4.0	0.8
Easily hydrolyzable carbohydrates	4.6	2.3	2.5	1.7
Cellulose	3.6	2.2	1.6	1.3
Lignin	10.2	4.7	3.8	2.9
Total carbohydrates	20.7	9.5	13.3	7.8
Number of culms per 100 gm	20	30	54	60
Average length of culms, cm	47	44	33	38
Total length of culms, cm	940	1320	1782	2280

TABLE 11.—Temperature in Relation to Constituents per Unit Length of Oat and Wheat Culms. 1924

Material	Oats			Wheat		
	Open	Protected by glass		Open	Protected by glass	
		Cover	Inclosure		Cover	Inclosure
	mg.	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*
Moisture	82.2	65.3	47.7	39.6	31.9	31.5
Dry matter	24.2	16.5	9.9	18.3	11.2	8.8
Total nitrogen	0.11	0.09	0.06	0.03	0.03	0.02
Free reducing sugars	1.9	0.6	0.3	0.9	0.5	0.4
Inverted sugars	0.4	0.4	0.2	5.2	2.5	0.8
Easily hydrolyzable carbohydrates	4.6	2.8	1.7	3.6	2.1	1.9
Cellulose	3.6	2.8	1.8	2.5	1.9	1.7
Lignin	10.2	6.9	4.1	4.8	3.8	3.1
Total carbohydrates	20.9	13.6	8.2	16.9	10.8	8.0
Number of culms per 100 gm	20	26	34	48	61	62
Average length of culms, cm	47	47	51	36	38	40
Total length of culms, cm	940	1222	1734	1728	2318	2480

The dry matter per unit length of culm in the plants having a low carbohydrate content was 71 per cent of that in the plants having a high carbohydrate content in the oats and 48 per cent in the wheat in the sand-soil-manure test; 48 per cent and 68 per cent in the oats and wheat, respectively, in the shading tests, and 41 per cent and 48 per cent in the oats and wheat, respectively, in the temperature tests.

DRY MATTER PER UNIT LENGTH OF CULM IN RELATION TO DIAMETER OF CULMS

Wherever oat and wheat plants are for any reason crowded, there is a tendency toward the development of slender culms; although the chemical composition of these may not differ materially from larger ones, yet, on account of the smallness of the diameter, the dry matter per unit length is relatively low, and the stems, therefore, are accordingly weak and frequently lodge.

Rate of seeding.—In 1924 samples were gathered from oats seeded at the rates of 4, 14, and 24 pecks per acre and from wheat sown at the rates of 3 and 10 pecks per acre. The analytical results shown in Table 12 do not indicate consistent differences in any of

TABLE 12.—Rate-of-Seeding in Relation to Composition of Oat and Wheat Culms. 1924

Material	Rate of seeding per acre—pecks				
	Oats			Wheat	
	4	14	24	3	10
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Moisture	80.4	79.5	80.9	73.5	72.8
Dry matter	19.6	20.5	19.1	26.5	27.2
Total nitrogen	0.069	0.062	0.067	0.126	0.104
Free reducing sugars	1.8	1.7	1.1	8.5	6.2
Inverted sugars	0.3	0.6	0.9	0.1	0.0
Easily hydrolyzable carbohydrates	3.2	3.3	3.3	5.5	5.1
Cellulose	2.9	3.5	3.2	3.1	4.0
Lignin	8.6	8.7	7.9	8.4	9.0
Total carbohydrates	16.8	17.8	16.4	25.6	24.3

the constituents. On account of the reduced size in diameter of the culms, however, due to the heavier rates of seeding, there was a material reduction in the quantity of all the constituents when they were calculated to unit length of culm, Table 13.

Size of seed.—Similar results may be obtained from the use of large and small seeds, for in a bushel of the latter the number of individual seeds is much greater; if both, therefore, are sown at the

TABLE 13.—Rate-of-Seeding in Relation to Constituents per Unit Length of Oat and Wheat Culms. 1924

Material	Oats			Wheat	
	4	14	24	3	10
	mg.	*mg.*	*mg.*	*mg.*	*mg.*
Moisture	99.2	67.9	37.5	56.7	30.6
Dry matter	24.2	17.5	8.8	20.4	11.4
Total nitrogen	0.08	0.05	0.03	0.09	0.04
Free reducing sugars	2.2	1.4	0.5	6.6	2.6
Inverted sugars	0.4	0.5	0.4	0.1	0.0
Easily hydrolyzable carbohydrates	3.9	2.8	1.5	4.2	2.1
Cellulose	3.6	3.0	1.5	2.4	1.7
Lignin	10.6	7.4	3.7	6.5	3.8
Total carbohydrates	20.7	15.2	7.6	19.8	10.2
Number of culms per 100 gm.	18	30	60	35	58
Average length of culms, cm.	45	39	36	37	41
Total length of culms, cm.	810	1170	2160	1295	2378

same rate, the use of the small will result in many more but smaller culms per acre. Large and small oats, the calculated number of seeds per bushel being 779,520 for the former and 1,835,520 for the latter, were sown at the rates of 4, 14, and 24 pecks per acre in 1924. The composition of the culms given in Table 14 does not show a

TABLE 14.—Size of Seed in Relation to Composition of Oat Culms. 1924

Material	4-peck rate		14-peck rate		24-peck rate	
	Large	Small	Large	Small	Large	Small
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Moisture	81.8	79.6	78.3	77.5	78.7	78.5
Dry matter	18.2	20.4	21.7	22.5	21.3	21.5
Total nitrogen	0.068	0.062	0.067	0.056	0.073	0.056
Free reducing sugars	1.5	1.8	1.5	1.5	1.5	1.8
Inverted sugars	0.6	0.9	1.8	1.5	1.7	1.1
Easily hydro. carbohydrates	3.1	3.4	3.8	3.9	4.0	3.6
Cellulose	2.9	3.0	3.1	3.2	3.0	3.4
Lignin	7.8	8.5	8.6	8.6	8.5	9.3
Total carbohydrates	15.9	17.6	18.8	18.7	18.7	19.2

material or consistent difference in any of the constituents between the large and small seeds, but on account of the reduced size of culms grown from the latter, there was in them a marked reduction in all the constituents when these results were calculated to unit length of culm as shown in Table 15.

Varieties.—Culms small in diameter due to a crowded stand may result from the variety used, for these differ materially in their proclivity to tiller. In general, the so-called stiff-strawed varieties tiller less than do the so-called weak-strawed ones. Carefully selected choice seeds of stiff and weak varieties were space

TABLE 15.—Size of Seed in Relation to Constituents per Unit Length of Oat Culms. 1924

Material	4-peck rate		14-peck rate		24-peck rate	
	Large	Small	Large	Small	Large	Small
	mg.	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*
Moisture	100.1	61.8	63.1	31.7	38.0	27.9
Dry matter	22.3	15.8	17.5	9.2	10.3	7.7
Total nitrogen	0.08	0.05	0.05	0.02	0.03	0.02
Free reducing sugars	1.8	1.4	1.2	0.6	0.7	0.6
Inverted sugars	0.7	0.7	1.5	0.6	0.8	0.4
Easily hydro. carbohydrates	3.8	2.6	3.1	1.6	1.9	1.3
Cellulose	3.6	2.3	2.5	1.3	1.4	1.2
Lignin	9.5	6.6	6.9	3.5	4.1	3.3
Total carbohydrates	19.5	13.6	15.1	7.6	9.0	6.8
No. culms per 100 gm.	19	33	31	74	56	78
Av. length of culms, cm.	43	39	40	33	37	36
Total length of culms, cm.	817	1287	1240	2442	2072	2808

TABLE 16.—Tillering of Stiff- and Weak-strawed Varieties of Oats

Class	Variety	Total		Average		Best culm	
		Plants No.	Culms No.	Culms No.	Wt. of plant Gm.	Height Cm.	Diameter Mm.
			1920				
Stiff	Alaska Selection	171	1125	6.6	19.7	126.1	4.2
	Ohio 201	418	1948	4.6	16.7	138.7	4.0
	Siberian Selection	208	1476	7.1	36.6	133.0	4.0
	Storm King	363	1383	3.8	10.3	107.1	4.3
	Victory	411	1722	4.1	10.7	122.9	3.5
	Average	314.2	1530.8	5.2	18.8	125.6	4.0
Weak	Alaska Selection	165	1663	10.1	17.4	124.5	3.7
	Ohio 7009	431	3319	7.7	7.0	105.9	3.1
	Siberian Selection	150	1417	9.5	23.7	121.8	3.5
	Silvermine	371	2422	6.5	11.5	121.4	3.5
	Wideawake	391	2803	7.1	16.5	129.7	3.5
	Average	301.6	2324.8	8.2	15.2	120.6	3.4
			1921				
Stiff	Black Mogul	429	2973	6.9	13.3	89.1	4.0
	Ohio 201	439	2152	4.9	14.9	79.3	3.6
	Sparrowbill	424	2691	6.3	13.7	91.8	3.6
	Victory	414	3061	7.4	14.0	92.5	3.9
	Average	428.5	2719.3	6.3	14.0	88.2	3.8
Weak	Daubaney	407	2989	7.3	8.2	77.5	2.7
	Ohio 7009	356	2604	7.3	15.0	84.9	3.1
	Siberian (16219)	386	3131	8.1	10.7	86.8	3.4
	Wideawake	436	3084	7.0	11.3	88.1	2.9
	Average	396.3	2952.	7.4	11.3	84.3	3.0

TABLE 16.—Tillering of Stiff- and Weak-strawed Varieties of Oats—Continued

Class	Variety	Total: Plants No.	Total: Culms No.	Average: Culms No.	Average: Wt. of plant Gm.	Best culm: Height Cm.	Best culm: Diameter Mm.
			1922				
Stiff	Black Mesdag	373	1763	4.7	....	124.7	5.2
	Black Mogul	450	2594	5.8	20.3	117.1	4.6
	Canadian	347	1439	4.1	22.9	126.3	4.6
	Ohio 201	415	1563	3.7	24.5	132.7	4.7
	Sparrowbill	308	1498	4.8	25.4	120.5	5.1
	Storm King	430	1810	4.2	20.1	117.1	4.6
	Tartar King	335	1196	3.5	19.9	107.9	4.6
	Victory	386	1903	4.9	20.2	118.1	4.5
	Average	380.5	1720.7	4.4	21.9	120.6	4.8
Weak	Alaska	466	2316	5.0	20.7	127.7	4.0
	Burt	409	2913	7.1	....	104.7	3.4
	Daubaney	346	1861	5.3	16.9	101.5	3.5
	Joanette	430	3789	8.8	....	101.5	3.7
	Ohio 7009	445	2404	5.4	20.6	109.3	4.8
	Siberian (16219)	422	1779	4.2	23.1	123.4	4.8
	Silvermine	465	2140	4.6	18.4	110.9	4.1
	Wideawake	449	2167	4.8	22.3	132.4	4.0
	Average	429.0	2421.1	5.6	20.3	113.9	4.0
			1923				
Stiff	Black Mesdag	303	1204	3.9	....	....	....
	Black Mogul	347	2494	7.1	....	....	....
	Canadian	322	2229	6.9	....	....	....
	Ohio 201	390	1840	4.7	....	....	....
	Sparrowbill	304	1569	5.1	....	....	....
	Storm King	383	1585	4.1	....	....	....
	Tartar King	259	1133	4.3	....	....	....
	Victory	404	2505	6.2	....	....	....
	Average	339	1819.9	5.3	....	....	....
Weak	Alaska	420	2907	6.9	....	....	....
	Burt	393	3110	7.9	....	....	....
	Daubaney	329	1699	5.1	....	....	....
	Joanette	295	3743	12.6	....	....	....
	Ohio 7009	161	1484	9.2	....	....	....
	Siberian (16219)	407	2037	5.0	....	....	....
	Silvermine	402	2277	5.6	....	....	....
	Wideawake	418	2525	6.0	....	....	....
	Average	353	2472.8	7.3	....	....	....

planted (8 inches apart each way) on fertile, uniform soil. The results obtained with oats are given in Table 16 and with wheat, in Table 17.

In both oats and wheat and in each year the average number of culms per plant in the group of stiff varieties was less than was that in the group of weak varieties, although in some cases the differences were not marked. Not all the varieties, either of oats or wheat, were as outstanding in their class as was desired, but

TABLE 17.—Tillering of Stiff- and Weak-strawed Varieties of Wheat

Class	Variety	Total		Average		Best culm	
		Plants No.	Culms No.	Culms No.	Wt. of plant Gm.	Height Cm.	Diam. Mm.
	1921						
Stiff	American Bronze	383	4583	11.9	21.8	108.3	3.8
	Dawson's Golden Chaff	365	4470	12.2	23.1	108.5	3.4
	Fultzo-Mediterranean	321	3887	12.1	21.7	96.4	3.4
	Gladden	358	4585	12.8	25.3	112.3	3.4
	Average	356	4381.3	12.3	23.0	106.4	3.5
Weak	Fultz selection	346	3688	10.6	17.3	91.5	3.1
	Mediterranean	341	4675	13.7	26.3	113.0	3.3
	Poole selection	400	4770	11.9	24.4	115.1	3.3
	Turkey Red	337	5132	15.2	22.3	93.8	3.0
	Average	356	4566.3	12.8	22.5	103.3	3.2
	1922						
Stiff	American Bronze	440	3819	8.6	....	....	....
	Dawson's Golden Chaff	426	4500	10.5	....	....	....
	Fultzo-Mediterranean	425	4021	9.4	....	....	....
	Gladden	423	4067	9.6	....	....	....
	Prosperity	438	3363	7.6	....	....	....
	Average	430.4	3954	9.2	....	....	....
Weak	Budapest	458	3966	8.6	....	....	....
	Mediterranean	436	4549	10.4	....	....	....
	Ohio 15095	326	4789	14.7	....	....	....
	Ohio 18331	417	4810	11.5	....	....	....
	Turkey Red	416	5063	12.1	....	....	....
	Average	410.6	4635.4	11.5	....	....	....
	1923						
Stiff	American Bronze	544	3517	6.4	....	....	....
	Dawson's Golden Chaff	512	3078	6.0	....	....	....
	Fultzo-Mediterranean	481	3043	6.3	....	....	....
	Gladden	508	3326	6.5	....	....	....
	Ohio 16047	515	4133	8.0	....	....	....
	Average	512	3419.4	6.6	....	....	....
Weak	Budapest	477	3600	7.5	....	....	....
	Mediterranean	374	3252	8.6	....	....	....
	Ohio 15095	515	4884	9.5	....	....	....
	Ohio 18210	443	3989	9.0	....	....	....
	Turkey Red	347	2856	8.2	....	....	....
	Average	431.2	3716.2	8.5	....	....	....

they were the best available. Between oat varieties like Storm King, which is notably stiff, and the Wideawake, which is moderately weak, the difference in number of culms produced per plant each year was quite marked. The difference was also pronounced between such wheat varieties as the American Bronze, on the one hand, and the Turkey Red, on the other. The relationship becomes, perhaps, more impressive by reason of the fact that it holds not only between varieties, but also between pure-line strains of the same variety as indicated by the Alaska and Siberian selections of oats in 1920, Table 16.

The smaller number of culms in the stiff-strawed groups was not due to relatively smaller plants. On the contrary, the average weight of plants and the average height and diameter of the best culm selected from these plants, so far as these data are available, indicate that they were larger.

The averages given for each group of varieties are not altogether comparable because the figures upon which they are based are themselves averages, and these are based on the performance of an unequal number of plants, the number in each case being given in the left hand column of the tables. A more precise presentation is given in Table 18, the figures of which are based on the performance of all the plants for all the years summarized as a single group for each class.

TABLE 18.—Tillering of Stiff- and Weak-strawed Varieties of Oats and Wheat—Summary

Class	Oats			Wheat		
	Total number of		Av. No. of culms per plant	Total number of		Av. No. of culms per plant
	Plants	Culms		Plants	Culms	
Stiff	9033	46,856	5.2	6139	54,394	8.9
Weak	9150	62,583	6.8	5633	60,023	10.7

Considering the oats, the weak-strawed varieties exceeded the stiff-strawed varieties by 1.6 culms per plant, or 31 per cent. This difference is based on the performance of 18183 plants, 9033 stiff-strawed individuals involving ten varieties and 9150 weak-strawed ones involving eight varieties. Both classes, but not all varieties, were grown in four different seasons.

Considering the wheat, the weak-strawed varieties exceeded the stiff-strawed ones by 1.8 culms per plant, or 20 per cent. This difference is based on the performance of 11,772 plants; 6139 stiff-strawed individuals involving six varieties and 5633 weak-strawed ones involving eight varieties. Both classes, but not all varieties, were grown in three different seasons.

Weak varieties tend to develop a thick stand through prolific tillering, but, as in the rate-of-seeding and size-of-seed tests, no consistent difference in chemical composition in relation to thickness of stand was found. Three of the most outstanding varieties of each class of oats and wheat were analyzed and the results summarized in Table 19.

TABLE 19.—Varieties in Relation to Composition of Culms

	Stiff-strawed			Weak-strawed		
Oats						
Material	Ohio 201	Victory	Storm King	Wide-awake	Joanette	Silver-mine
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Moisture	82.6	81.5	81.4	76.9	79.7	79.7
Dry matter	17.4	18.5	18.6	23.1	20.3	20.3
Total nitrogen	0.083	0.065	0.074	0.049	0.062	0.115
Free reducing sugars	2.3	2.1	2.2	4.2	1.7	2.2
Inverted sugars	0.3	0.8	1.8	0.0	0.7	0.4
Easily hydrolyzable carbohydrates	3.5	3.4	3.3	4.4	4.2	4.0
Cellulose	2.5	2.7	2.6	3.1	3.2	3.1
Lignin	6.7	7.3	6.9	9.7	8.1	8.1
Total carbohydrates	15.3	16.3	16.8	21.4	17.9	17.8
Wheat						
	Dawson's Golden Chaff	American Bronze	Fultzo-Mediterranean	Turkey Red	Budapest	Mediterranean
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Moisture	71.6	71.7	72.9	74.0	70.7	72.6
Dry matter	28.4	28.3	27.1	26.0	29.3	27.4
Total nitrogen	0.097	0.087	0.090	0.077	0.071	0.086
Free reducing sugars	1.5	8.6	1.4	1.7	2.2	1.6
Inverted sugars	6.4	0.0	6.1	7.4	6.4	5.5
Easily hydrolyzable carbohydrates	5.2	5.2	5.1	5.7	5.6	5.1
Cellulose	3.8	3.6	3.5	3.5	3.4	3.5
Lignin	9.0	9.1	8.6	9.2	9.2	9.1
Total carbohydrates	25.9	26.5	24.7	27.5	26.8	24.8

Estimating the constituents on the basis of a unit length of culm, however, as shown in Table 20, the weak varieties in both cases were without exception inferior to the stiff in dry matter and in total carbohydrates, including the easily hydrolyzable carbohydrates, cellulose, and lignin.

Diameter, breaking strength, and solidity.—The inferiority in strength of culms grown in a crowded condition, whether due to rate-of-seeding, size-of-seed, or varieties, is indicated not only by their chemical composition but also by their physical characteristics; i. e., by their diameter, breaking strength, and solidity. Results of these determinations made on culms gathered at heading time were as shown in Table 21.

TABLE 20.—Varieties in Relation to Constituents per Unit Length of Culm

	Stiff-strawed			Weak-strawed		
	Oats					
Material	Ohio 201	Victory	Storm King	Wide-awake	Joanette	Silver-mine
	mg.	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*
Moisture	114.4	101.9	129.2	63.1	63.6	48.6
Dry matter	24.1	23.1	29.5	19.0	16.2	12.4
Total nitrogen	0.115	0.081	0.117	0.040	0.049	0.070
Free reducing sugars	3.2	2.6	3.5	3.4	1.3	1.3
Inverted sugars	0.4	1.0	2.8	0.0	0.5	0.2
Easily hydrolyzable carbohydrates	4.8	4.3	5.2	3.6	3.3	2.4
Cellulose	3.5	3.4	4.1	2.5	2.5	1.9
Lignin	9.3	9.1	10.9	7.9	6.4	5.0
Total carbohydrates	21.2	20.4	26.6	17.6	14.3	10.8
Number of culms per 100 gm	38	40	35	42	38	39
Average length of culms, cm	19	20	18	29	33	42
Total length of culms, cm	722	800	630	1218	1254	1638
	Wheat					
	Dawson's Golden Chaff	Ameri-can Bronze	Fultzo-Mediter-ranean	Turkey Red	Buda-pest	Mediter-ranean
	mg.	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*
Moisture	56.9	46.8	59.6	37.0	37.9	38.6
Dry matter	22.6	18.5	22.1	13.0	15.7	14.6
Total nitrogen	0.077	0.057	0.074	0.038	0.038	0.046
Free reducing sugars	1.2	5.6	1.2	0.8	1.2	0.8
Inverted sugars	5.1	0.0	5.0	3.7	3.4	2.9
Easily hydrolyzable carbohydrates	4.1	3.4	4.2	2.9	3.0	2.7
Cellulose	3.0	2.4	2.9	1.8	1.8	1.9
Lignin	7.2	6.0	7.0	4.6	4.9	4.8
Total carbohydrates	20.6	17.3	20.3	13.8	14.3	13.2
Number of culms per 100 gm	34	45	34	50	49	47
Average length of culms, cm	37	34	36	40	38	40
Total length of culms, cm	1258	1530	1224	2000	1862	1880

TABLE 21.—Relative Strength of Oat and Wheat Culms

Material	Oats			Wheat		
	Diam-eter	Breaking strength	Solidity	Diam-eter	Breaking strength	Solidity
	mm.	*gm.*	*gm.*	*mm.*	*gm.*	*gm.*
Shaded	3.44	603	81	2.62	199	53
Unshaded	4.27	966	104	2.73	283	68
Thin seeding	5.24	1329	135	3.34	573	91
Thick seeding	4.09	712	78	2.83	370	63
Large seeds	4.60	1115	100	....	....	....
Small seeds	3.60	690	78	....	....	....
Stiff Varieties: Ohio 201	4.68	1404	126	....	....	....
Stiff Varieties: Victory	4.85	1671	154	....	....	....
Weak Varieties: Joanette	3.44	603	81	....	....	....
Weak Varieties: Silvermine	3.97	939	105	....	....	....
Stiff Varieties: Nigger	....	....	....	3.73	846	75
Stiff Varieties: Fultzo-Med.	....	....	....	3.49	697	71
Stiff Varieties: Am. Bronze	....	....	....	3.40	694	62
Stiff Varieties: D. G. Chaff	....	....	....	3.37	726	62
Weak Varieties: Nigger 18943	....	....	....	3.21	386	40
Weak Varieties: Mediterranean	....	....	....	2.86	438	55
Weak Varieties: Turkey Red	....	....	....	2.58	414	49
Weak Varieties: Budapest	....	....	....	2.69	472	55

The culms grown under the more crowded conditions were relatively small in diameter, correspondingly weak in breaking strength, and less sturdy, as indicated by the solidity which represents the weight in grams of 100 sections each 10 cm. long.

The difference in size of these culms is illustrated in Figure 10 for thin and thick seedings of oats and wheat, in Figure 11 for large and small seed oats, in Figure 12 for stiff and weak varieties of oats, and in Figure 13 for stiff and weak varieties of wheat.

DRY MATTER IN RELATION TO THICKNESS OF CELL WALLS AND WIDTH OF ZONE OF HYPODERMAL OR SUPPORTING TISSUE

Cross sections made on oat and wheat culms grown under the various soil, climatic, and cultural conditions already enumerated showed that the situations which result in a low content of dry matter were associated always with thin-walled cells and a comparatively narrow zone of hypodermal or supporting tissue. Photomicrographs of typical segments of cross sections are shown in Figures 14 and 15 for the sand-soil-manure oats and wheat, respectively; in Figures 16 and 17 for the unshaded and shaded oats and wheat, respectively; in Figures 18 and 19 for the glass covered oats and wheat, respectively; in Figure 20 for the rate-of-seeding and size-of-seed oats; in Figure 21 for the rate-of-seeding wheat; in Figures 22 and 23 for stiff- and weak-strawed varieties of oats and wheat, respectively.

In the sand-soil-manure tests with oats and wheat, there was not much difference in the width of the hypodermal zone in the culms grown on the sand and on the manure, but in the former the cell walls were thicker and the tissue was much more completely lignified. From the analyses given in Table 6, differences in lignin would be expected.

In the shading test the zone of hypodermal tissue was slightly wider in the unshaded than in the shaded culms of oats. The unshaded culms were also characterized by a greater degree of lignification. A similar relationship was found between the unshaded and shaded culms of wheat.

In the temperature tests with oats and wheat, the cell walls were somewhat thicker in the culms covered with glass than in those inclosed with glass. The zone of hypodermal tissue, however, was in each case about the same.

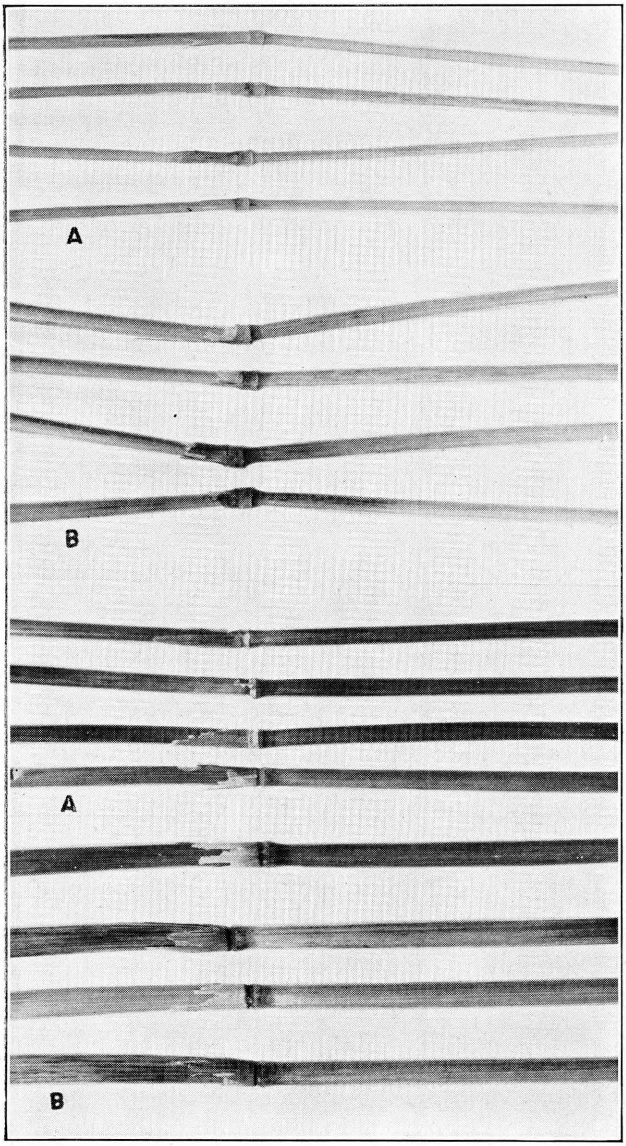

Fig. 10.—Above—Typical size of wheat culms grown from seedings at the rates of 10 pecks per acre (A) and 3 pecks per acre (B).

Below—Typical size of oat culms grown from seedings made at the rates of 14 pecks per acre (A) and 4 pecks per acre (B).

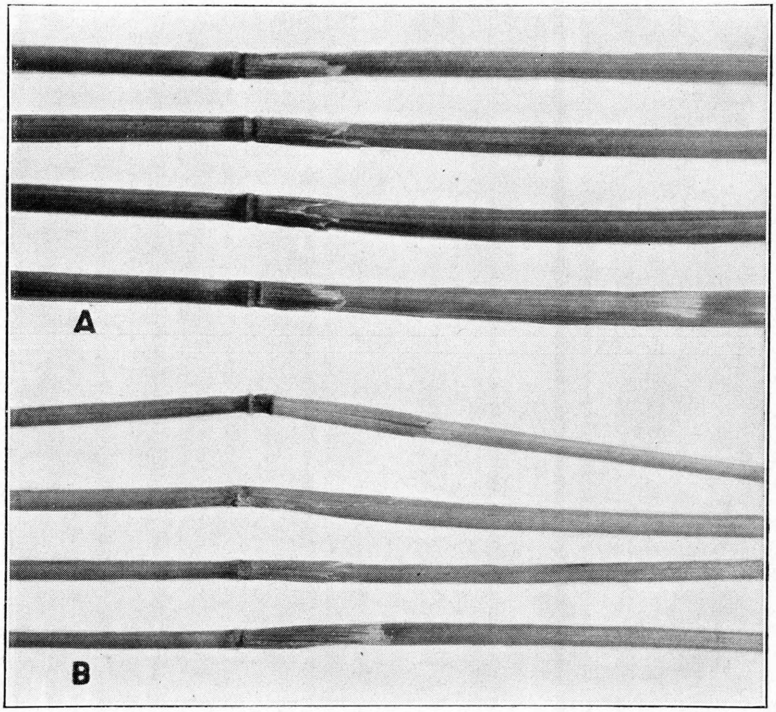

Fig. 11.—Typical size of oat culms grown from large (A) and from small (B) seeds, both classes being sown at the same rate per acre

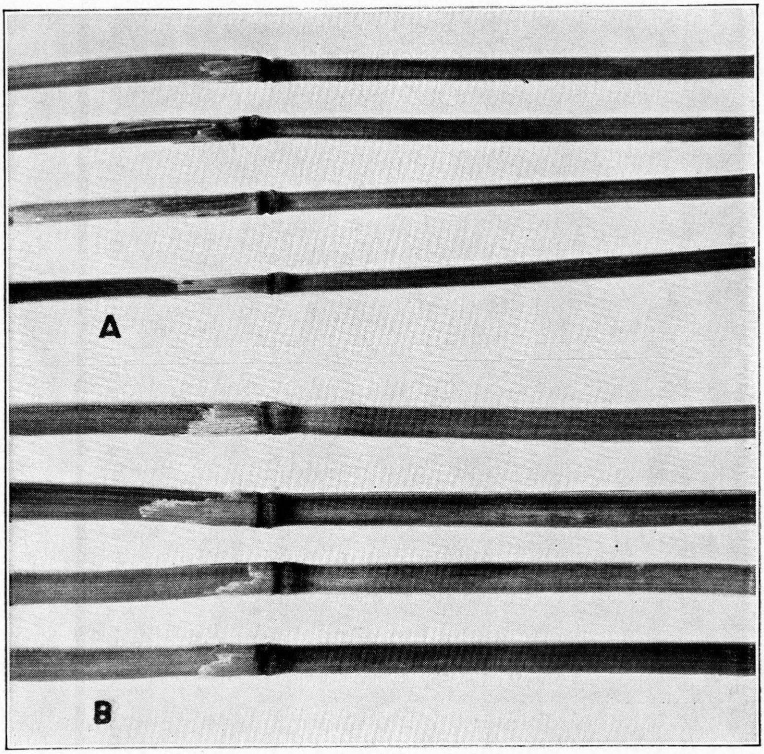

Fig. 12.—Culms of stiff- (B) and weak- (A) strawed varieties of oats

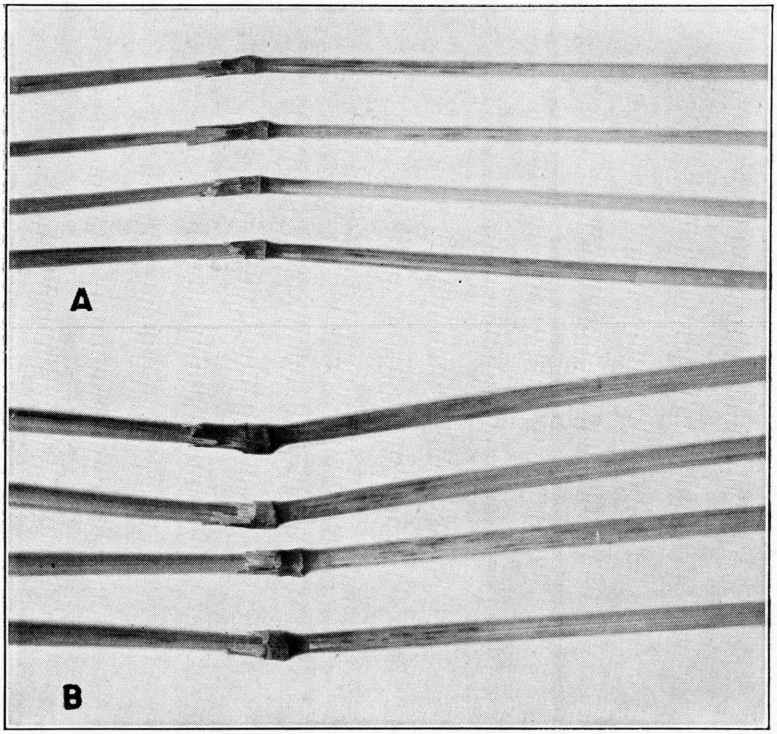

Fig. 13.—Culms of stiff- (B) and weak- (A) strawed varieties of wheat

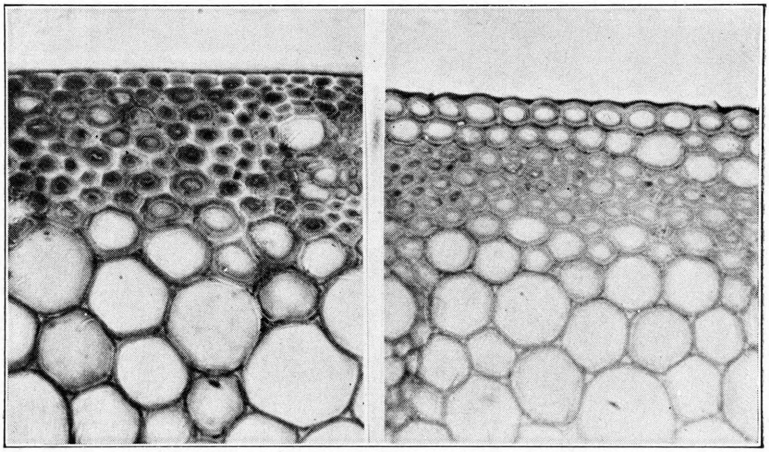

Fig. 14.—Typical segments of cross sections of oat culms grown in sand (left) and manure. x520

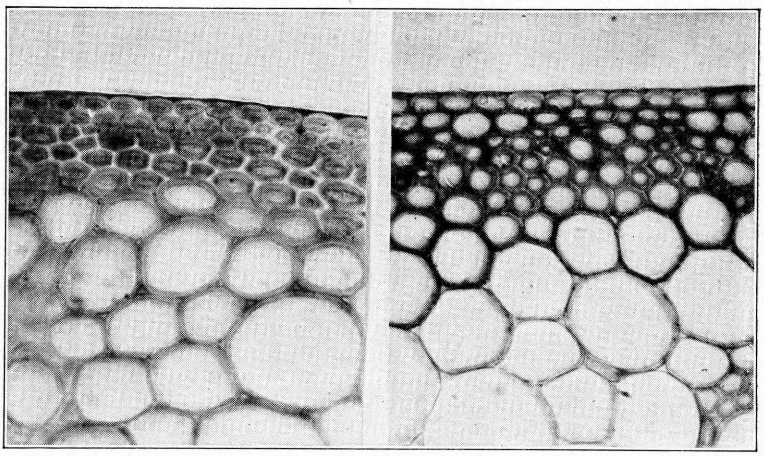

Fig. 15.—Typical segments of cross sections of wheat culms grown in sand (left) and manure. x520

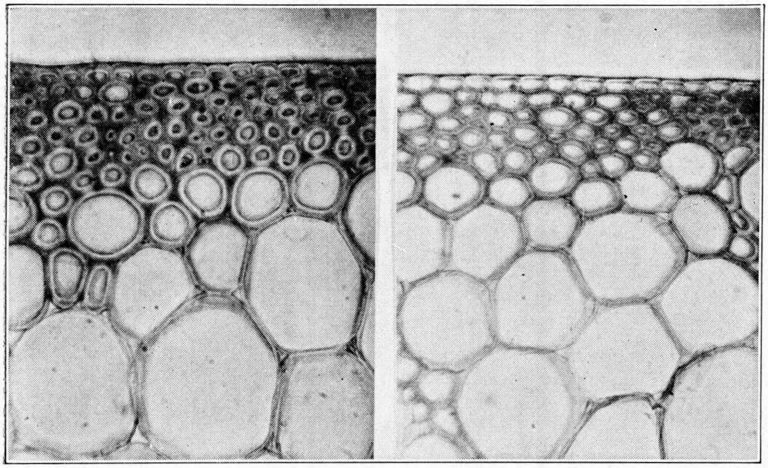

Fig. 16.—Typical segments of cross sections of unshaded (left) and shaded oat culms. x520

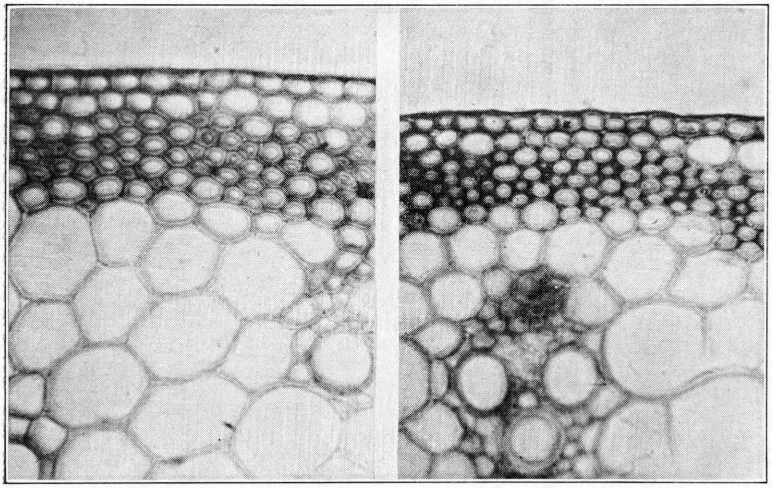

Fig. 17.—Typical segments of cross sections of unshaded (left) and shaded wheat culms. x520

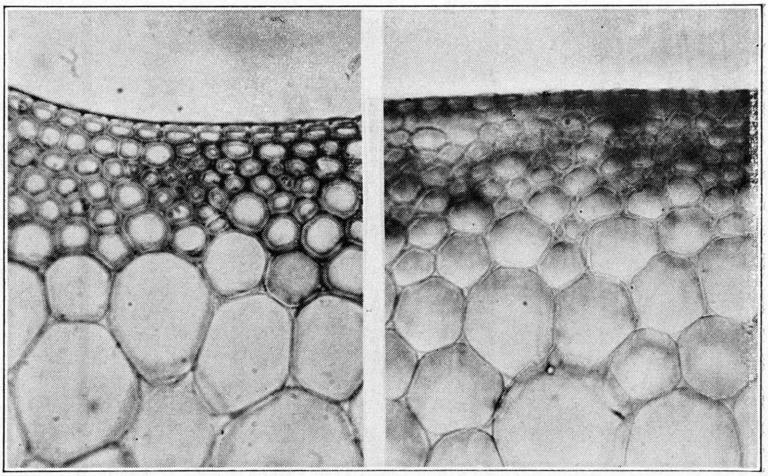

Fig. 18.—Typical segments of cross sections of oat culms grown under glass cover (left) and in glass inclosure. x520

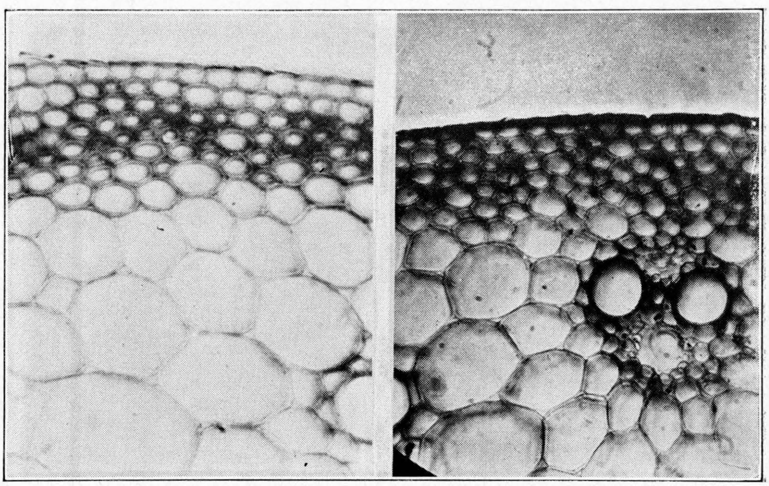

Fig. 19.—Typical segments of cross sections of wheat culms grown under glass cover (left) and in glass inclosure. x520

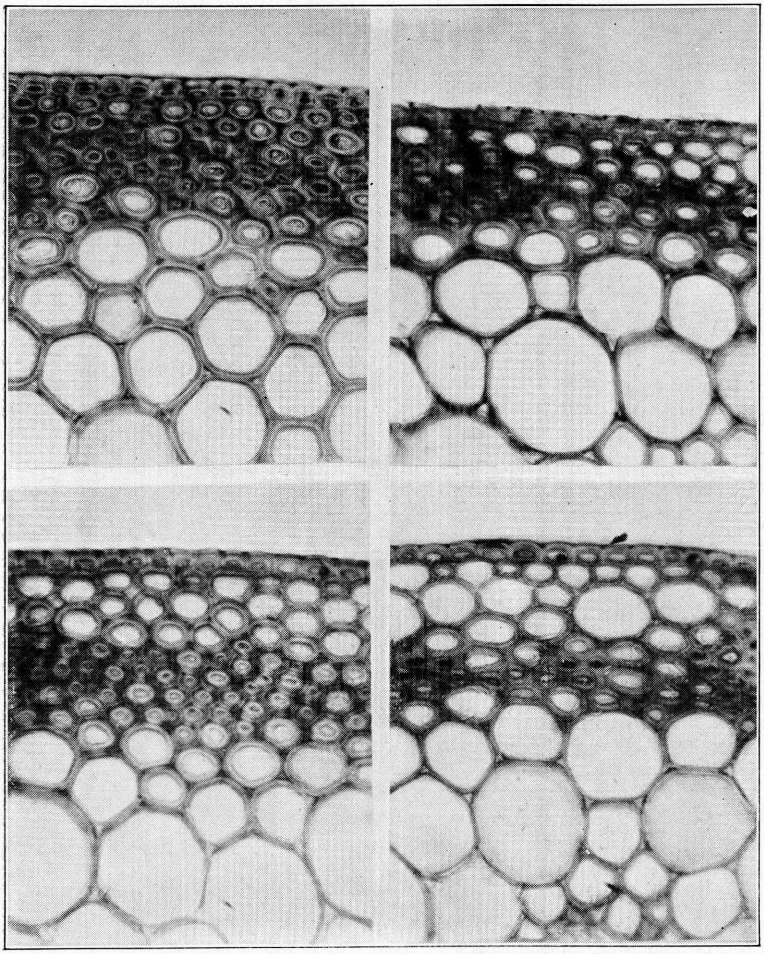

Fig. 20.—Typical segments of cross sections of oat culms grown from seed used at rates of 4 (left) and 14 pecks per acre. The two rates of seeding were made with large (above) and small seeds. x520.

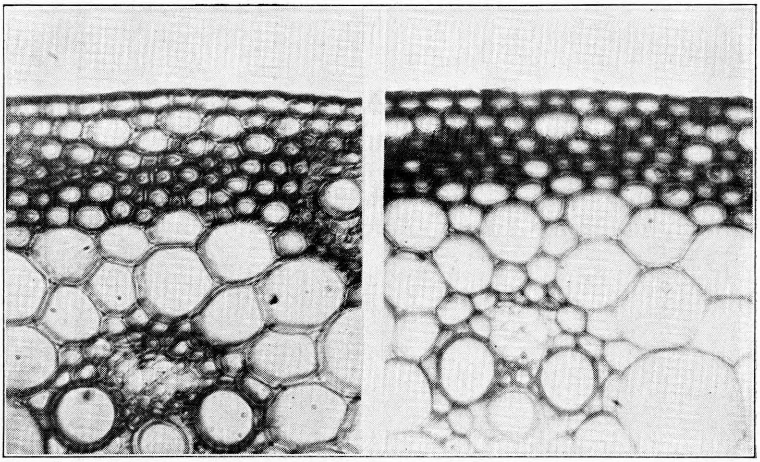

Fig. 21.—Typical segments of cross sections of wheat culms grown from seed used at rates of 3 (left) and 10 pecks per acre. x520

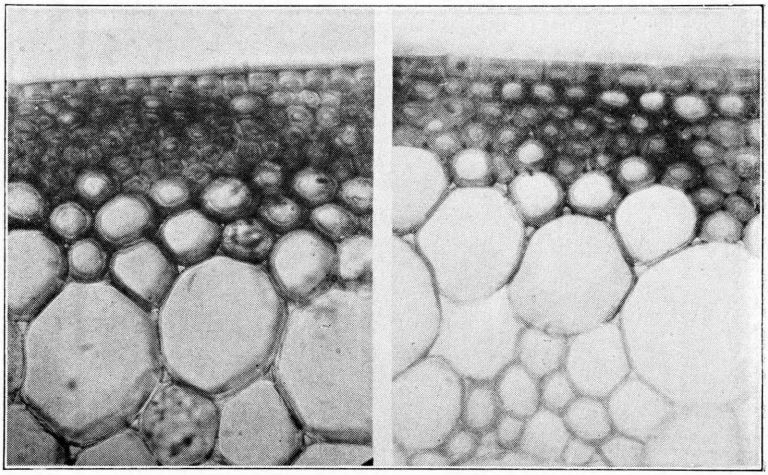

Fig. 22.—Typical segments of cross sections of stiff- (left) and weak-strawed varieties of oats. x520

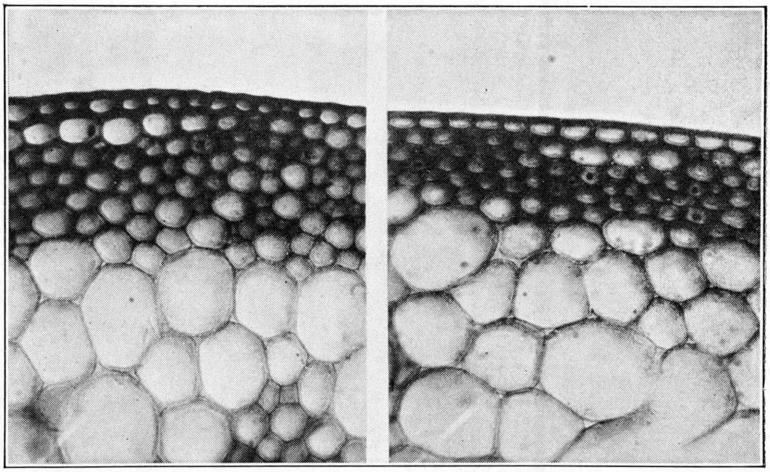

Fig. 23.—Typical segments of cross sections of stiff- (left) and weak-strawed varieties of wheat. x520

In the rate-of-seeding tests the zone of hypodermal tissue was wider and the cell walls were thicker, more completely lignified, and more compact in the thin than in the thick seedings of both oats and wheat. In the size-of-seed tests the walls were thicker and the cells more compact in the culms grown from the large than from the small seeds.

In the stiff- and weak-strawed varieties the zone of hypodermal tissue was wider and the cell walls were thicker in the stiff than in the weak ones.

The thickness of culm walls in oats and wheat, grown under the various conditions represented by the photomicrographs were measured on green material at heading time in 1924, and the results are shown in Table 22.

DISCUSSION

In the sheaves of oats and wheat the percentage of straw, or vegetative growth, was always higher in the lodged than in the erect ones (Tables 1 and 2). Further, the number of culms was always greater (Tables 3 and 4), this being in agreement with the work of Neppi (34). Chemical analyses showed that lodging was associated always with a low dry matter per unit length of culm (Tables 9, 10, 11, 13, 15, and 20). This is in agreement with the findings of Rivera (41) who, working with wheat, concluded that lodging was due to high water content of the tissue. The factors to which this situation is the index are, he says, the "true cause" of lodging. The low dry matter resulted, in some cases, from direct and, in the others, from indirect causes.

TABLE 22.—Width of Culm Walls in Oats and Wheat. 1924

Kind of Sample				Oats*	Wheat*
				mm.	*mm.*
Fertility	Poor soil			0.955	....
	Rich soil			0.781	....
Light	Unshaded			0.939	0.874
	Shaded			0.610	0.583
Temperature..	Open			0.939	0.689
	Glass cover			0.717	0.562
	Glass inclosure			0.435	0.484
Cultural Practices	Rate of seeding		4 pecks	1.091	....
			14 pecks	0.804	....
	Size of seed		Large	1.091	....
			Small	0.882	....
	Varieties of oats	Stiff	Ohio 201	1.126	....
			Storm King	1.067	....
			Victory	1.100	....
		Weak	Joanette	0.964	....
			Silvermine	0.960	....
			Wideawake	0.890	....
	Varieties of wheat	Stiff	American Bronze	....	0.970
			Dawson's Golden Chaff	....	1.298
			Fultzo-Mediterranean	....	1.196
		Weak	Budapest	....	0.967
			Mediterranean	....	0.679
			Turkey Red	....	0.872

*Average of 50 measurements.

Direct.—Considering first the cases resulting from direct causes (Tables 13, 15, and 20), it may be said that the low dry matter was in every case associated with a thick stand; for thick seeding, the use of small seeds or the choice of weak-strawed varieties resulted always in the establishment of a relatively thick stand of plants.

That varieties of oats vary in tillering capacity has been shown by such workers as Georgeson and Burtis (9), Zavitz (61), and Wright, McAlpine, and Paterson (60). These authors do not discuss the possibility of a relationship between tillering and lodging through the development of large, coarse, and hence strong culms on the part of the low tillering class and of small, slender, fine, and hence weak culms on the part of the high tillering class. In the case of Georgeson and Burtis (9), however, suggestive data are available. Among the 92 varieties of oats with which Georgeson and Burtis worked, the extremes found in tillering were 6.2 culms per plant, on the one hand, and 18.4 culms per plant, on the other. Of this number there were 26 varieties which had less than 8 culms per plant and 25 varieties which had 10 or more culms per plant.

In an earlier bulletin published by the same institution, Georgeson and Cottrell (10) described many of these varieties, including the character of the straw. In describing the straw of the 26 low tillering varieties, they classified it as "coarse" in 16 cases, "medium to coarse" in 4 cases, "medium" in 3 cases, "medium to fine" in 2 cases, and "fine" in one case. In describing the straw produced by the 25 high tillering varieties, they classified it as "coarse" in 3 cases, "medium to coarse" in 3 cases, "medium" in 3 cases, "medium to fine" in 9 cases, "fine" in 4 cases, and "slender" in 3 cases.

Notes regarding the tendency in these varieties to lodge would be interesting.

Williams (57), however, does not believe that fineness of stems is associated with lodging and coarseness of stem with non-lodging. As proof of the first belief, he cited the American 60-Day variety. This is interesting because in this country, or at least in Ohio at the Experiment Station, the 60-Day develops as a fairly fine-stemmed variety, and in seasons favorable for lodging it is among the first to fall down. This author appears to believe that thick stand is associated with lodging and cites instances which have come under his observation, but, on the other hand, he does not believe that thin stand is an assurance against lodging.

Leitch (25) is inclined to believe in the chains of sequence—prolific tillering, fine straw, and lodging, on the one hand, and sparse tillering, coarse straw, and non-lodging on the other. He cites the Sandy variety of oats as an example of the former and the Storm King as an example of the latter.

Speaking of the lodging properties of oats, Stapledon (46) writes: "Although lodging is much affected by seed rate and conditions, varieties have very different inherent capabilities in this respect. In the main, the multi-tillering varieties tend to lodge rather badly."

In discussing tillering in winter wheat, Grantham (11) writes: "It is interesting to note that the varieties with the stiffest straw do not tiller freely, while on the other hand, the varieties with very fine straw generally excel in number of tillers."

Indirect.—Taking up the situations resulting from indirect causes (Tables 9, 10, and 11), it may be seen that low dry matter was in every case associated with a reduction in total carbohydrates for each of the three modified environmental factors—hypernutrition, shading, and increased temperature—resulted in a reduction of these compounds, particularly the easily hydrolyzable carbohydrates and lignin.

In this connection, it is interesting to note that Albertoni and Bosinelli (1) concluded that the varieties of wheat most resistant to lodging were the ones containing in their stems and leaves the highest content of crude fiber. Geerts (8) also found about 3 per cent less sugar in lodged than in erect sugar cane.

As has already been stated, the plants with a lower, as contrasted with those having a higher, carbohydrate content were characterized by a preponderance of straw, or vegetative growth, and by lodging. From these results, therefore, the conclusion would seem to be warranted that the carbohydrate content of oats and wheat at heading time is an important internal factor in determining whether the character of growth shall be within limits predominantly vegetative or reproductive, and consequently a leading and perhaps the principal internal factor involved in lodging. Moreover, it would seem to follow also that, since the low carbohydrate content was induced by hypernutrition, by reduced light, and by increased temperature, that each of these was probably a causative environmental factor. Both of these suggestions are in accord with the conclusions of Klebs (17 and 18) whose exhaustive and brilliant work sheds much light on the development of plants, particularly on the relationship of the ends of the chain of sequence—the conditions of plant growth and plant performance. The central thought pervading all of Klebs' work is of interest in this connection, and it has been well stated by Pieters (38), as follows: "The idea underlying all of Klebs' work is that every species has a sum total of potentialities constituting the specific nature of that species, but that the chemical and physical conditions prevailing at any one time within the organism determine which of the particular forms that the species is capable of producing, shall appear, and that the inner condition may be controlled to an extent, at least, by regulating the external conditions. In other words, the changes in form which we witness in the course of the development of an individual are results of chemical and physical interactions."

In the temperature tests, the reduction in carbohydrates was due to a probable increase in the rate of respiration. Walster (53) and also Tottingham (51) found less polysaccharides in greenhouse plants grown at 20° C. than in those grown at 15° C. Wiley (56) found a similar correlation between sugar content of sugar beets and the latitude of the cooperating Experiment Stations, which he attributed to variations in temperature.

In the shading tests the reduction in carbohydrates was probably due to a retardation of photosynthetic activity. Koch (20) also found a reduction in carbohydrates and consequent lodging from the shading of rye. The shaded culms possessed large thin-walled cells and an etiolated condition in general, while the unshaded culms were characterized by small thick-walled cells.

In the sand-soil-manure tests the reduction in carbohydrates seems to have been linked to the balance between carbohydrates and nitrates, for as the nitrates and moisture were decreased, as in the sand section, the carbohydrates increased, and as the nitrates and moisture were increased, as in the manure section, the carbohydrates decreased. A dearth of moisture and mineral nutrients made for an accumulation of carbohydrates, a high carbohydrate-nitrogen relation, and a moderate vegetative growth which was characterized by rigid upright stems. On the other hand, an abundance of moisture and mineral nutrients, particularly nitrates, made for a reduction of carbohydrates, a low carbohydrate-nitrogen relation, and rather pronounced vegetative or straw growth which was characterized by soft, pliable stems and consequent lodging. This is in general agreement with the findings of Kraus and Kraybill (23), Woo (58), Work (59), and others.

Of significant interest in this connection are the comments of Russell (43) who writes as follows concerning the effect of nitrogenous fertilizer: "All cereals, however, produce too much straw if the nitrate supply is excessive, and the straw does not commonly stand up well, but is beaten down or lodged by wind and rain ..... Wheat shows increases in straw greater than those in grain as the nitrogen supply is increased."

McCall and Wanser (31) also found a higher correlation between nitrate nitrogen and straw than between nitrate nitrogen and grain.

PRACTICAL CONSIDERATIONS

The numerous cultural and fertility plots, at the Ohio Agricultural Experiment Station, on which oats and wheat are grown from year to year, afford opportunity to observe the lodging behavior of these crops in response to the interaction of all environmental factors—cultural, soil, and climatic. The material presented in this part of the bulletin is based on the teachings of these plots with reference to this condition and is included primarily to show the relationship between lodging and various cultural practices, to serve incidentally as an illustration of the correctness of the foregoing analysis of the lodging situation, and to suggest, perhaps, helpful remedial measures.

The material consists chiefly of oat and wheat yields, soil nitrate and moisture determinations, and weather records. In general, the plots on which the crops were grown were 16 feet wide and long enough to make one-twentieth or one-tenth of an acre. In many cases, the recorded yield of grain and straw did not give an accurate picture of the vegetative or straw growth because in lodged grain much of the crop, particularly the straw, is unavoidably lost. Consequently, these data are supplemented by others showing the number of culms per acre, for the latter also may be regarded as an indicator of vegetative growth. The estimates were obtained by a count of the stubble on areas one yard square; usually five areas on one-twentieth and ten on one-tenth acre plots were used.

The nitrate determinations were made on composite samples of soil consisting of four borings, each taken to a depth of approximately 7 inches. After sifting through a quarter-inch mesh sieve, a 200-gram sample was shaken with 1000 cc. of distilled water from $1\frac{1}{2}$ to 4 hours. Nitrate determinations in duplicate were made on the filtrate, using the modified Devarda reduction method. The results of the nitrate determinations are recorded in parts per million of dry soil.

Inasmuch as the lodging situation is characterized by low dry matter per unit length of culm, it follows that the remedy, so far as the condition may be corrected, is to increase the dry matter per unit length of culm. In general, this may be accomplished in two ways: (1) By increasing the diameter without material changes in percentage composition, and (2) by increasing the percentage composition with or without increase in diameter of culm. These situations are responsive to environmental factors and, so far as the latter are amenable to control, lodging can be minimized or prevented.

Diameter of Culms

So far as the diameter of culms is concerned, this is dependent chiefly on the stand of plants; the thinner the stand, the larger the culms. A thin stand may be secured in various ways.

Thin seeding.—Oats and wheat were seeded at different rates through a period of years, the chief object being to determine the quantity of seed required per acre for maximum yields. In these tests the rates varied by increments of 1 peck per acre. In the oat tests the extreme rates were 4 and 14 pecks; in the wheat, 3 and 10 pecks, inclusive. In some of the years of these tests the number of culms per acre was estimated and the results found are shown in Table 23.

TABLE 23.—Rate of Seeding in Relation to Culms per Acre

Year	Oats			Wheat		
	4 pk.	9 pk.	14 pk.	3 pk.	8 pk.	10 pk.
	No.	*No.*	*No.*	*No.*	*No.*	*No.*
1921	634,040	900,240	1,055,120	1,616,560	1,703,680	2,240,920
1922	774,400	880,880	1,408,440	....	....	....
1923	832,480	880,880	943,800	1,708,520	2,274,160	2,207,040
1924	551,760	740,520	919,600	....	....	....
Average	698,170	850,630	1,081,740	1,662,540	1,998,920	2,223,980

As might be expected, the number of culms increased as the rate of seeding increased. The effect of rate of seeding on diameter of culms was noted in Table 21 and was illustrated in Figure 10. The effectiveness of these large culms in resisting lodging is frequently well illustrated in rate-of-seeding tests. In 1920, for example, lodging in oats on the Station farm was very prevalent, but in the rate-of-seeding test the thinner rates remained erect and the thicker ones lodged badly. The difference between the extremes, 4 and 14 pecks per acre, is shown in Figure 24.

Serious lodging rarely occurs in the thinner rates of seeding, but, of course, the yields from these rates, from year to year, are somewhat lower. In oats, as an average of 28 years, the 11-peck rate gave the highest net yield, 54.8 bushels, and the 5-peck rate reduced the yield 5.5 bushels; the 4-peck rate, 7.6 bushels. In wheat the 8-peck rate, as an average of 26 years, gave the highest net yield, 30.3 bushels, and this was reduced by the 4- and 3-peck rates by 2.2 and 3.7 bushels, respectively. On fertile soil, particularly lowlands where lodging is troublesome, it is probable that from that cause the loss in yield, to say nothing of the inconvenience in handling, is often greater than would result from thin seeding.

Large seeds.—In an oat test, the chief object of which was to determine the relative value of large and small kernels for seed purposes, the difference in size of seeds sown each year was such as could be obtained by passing oats repeatedly through a good fanning mill. On the average, a bushel of the small seeds contained approximately twice as many individual kernels as a bushel of the large. In a few seasons the number of culms per acre was estimated and the results obtained are tabulated in Table 24.

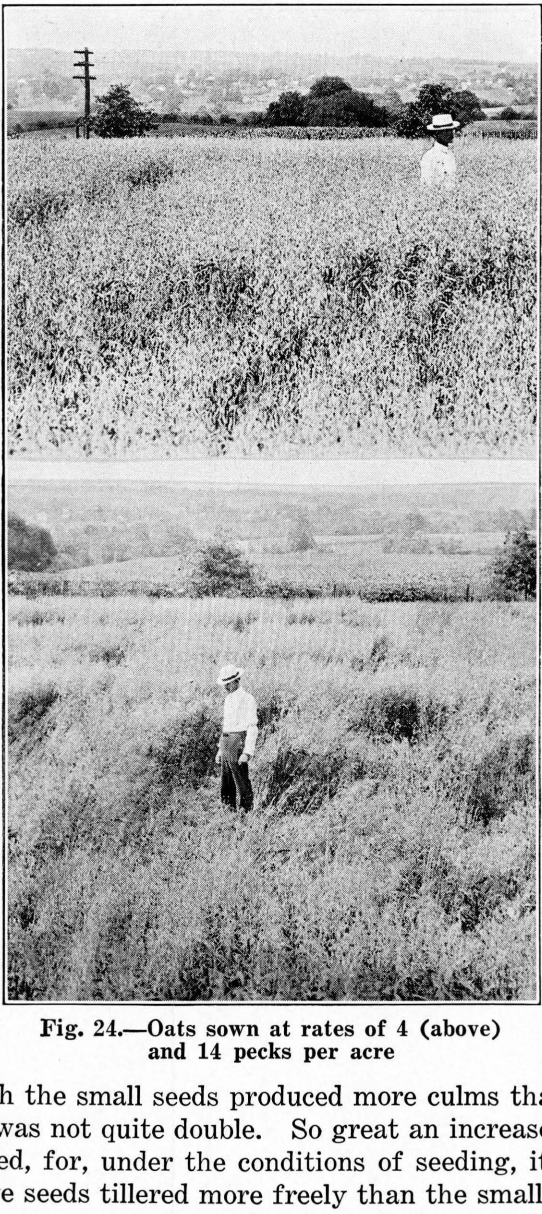

Fig. 24.—Oats sown at rates of 4 (above) and 14 pecks per acre

Although the small seeds produced more culms than the large, the number was not quite double. So great an increase was hardly to be expected, for, under the conditions of seeding, it is probable that the large seeds tillered more freely than the small.

TABLE 24.—Size of Seed in Relation to Culms per Acre

Year	Large	Small
	No.	*No.*
1920	1,258,400	2,182,840
1921	1,030,920	1,711,440
1922	938,960	1,427,800
1924	672,760	1,355,200
4-year average	975,260	1,669,320

The difference in size of culms resulting from the use of large and small seeds was noted in Table 21 and was illustrated in Figure 11. The resistance of the larger culms to lodging is frequently quite marked, as shown in Figure 25. Moreover, the larger seeds yielded, as an average of 17 years, 60.9 bushels, or 7.3 bushels more than the small seeds.

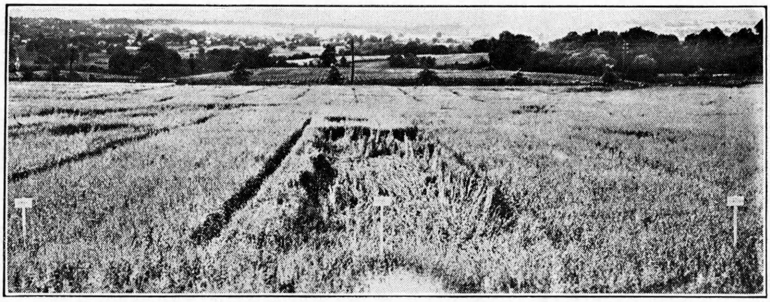

Fig. 25.—Oats grown from large (left), small (middle), and unscreened seeds (right)

Varieties.—Years of observation of many varieties of oats and wheat grown side by side on uniform land in experimental work have revealed a marked difference in ability to resist lodging, not only among varieties but among different strains of the same variety. Furthermore, experimental evidence, as noted in Tables 16 to 18, inclusive, indicates a tendency on the part of weak-strawed varieties to tiller more prolifically than the stiff-strawed ones. Moreover, as noted in Figures 12 and 13, the culms produced by the weak-strawed varieties were relatively smaller than the stiff-strawed ones. The relatively small size of culms of weak-strawed varieties may be an inherent characteristic or it may be due to crowding, for the stand of weak-strawed varieties was usually thicker than that of stiff-strawed ones. The estimated number of culms per acre produced by a few stiff- and weak-strawed varieties of oats and wheat in 1921 to 1924, inclusive, were as shown in Table 25.

TABLE 25.—Varieties in Relation to Culms per Acre

Oats					
Year	Stiff-strawed		Weak-strawed		
	Ohio 201	Victory	Joanette	Silvermine	Wideawake
	No.	*No.*	*No.*	*No.*	*No.*
1921	1,606,880	1,510,080	1,650,440	1,597,200	1,592,360
1922	1,205,160	1,132,560	1,766,600	1,389,080	1,418,120
1923	977,680	1,369,720	2,071,520	1,558,480	1,645,600
1924	730,840	1,122,880	1,369,720	861,520	943,800
4-year average	1,130,140	1,283,810	1,714,570	1,351,570	1,399,970

Wheat					
	Stiff-strawed			Weak-strawed	
	American Bronze	D. G. Chaff	Fultzo-Mediterranean	Mediterranean	Turkey Red
	No.	*No.*	*No.*	*No.*	*No.*
1921	1,369,720	1,718,200	1,897,280	1,969,880	1,902,120
1922	1,742,400	1,989,240	1,747,240	2,008,600	1,694,000
1923	2,148,960	2,332,880	2,178,000	2,226,400	2,395,800
1924	1,882,760	1,587,520	1,669,800	2,076,360	1,965,040
4-year average	1,785,960	1,906,960	1,873,080	2,070,310	1,989,240

Of course, the greater number of culms per acre secured by the use of weak-strawed varieties might be due to the sowing of a larger number of individual seeds providing smallness of seeds is a characteristic of weak-strawed varieties. This, however, is not the general rule. Some weak-strawed varieties have large kernels. The Mediterranean variety of wheat, for example, is not generally grown because the straw is weak, but it is notable for its large berry of high quality.

Contrast, as regards lodging, between varieties of small grain is illustrated in Figure 26.

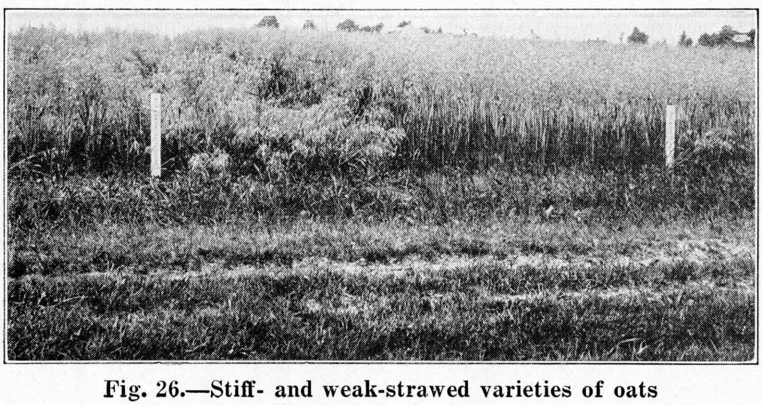

Fig. 26.—Stiff- and weak-strawed varieties of oats

Depth of planting in relation to stand.—Deep planting apparently has no effect on the tillering of oat and wheat plants and hence is not effective in inducing a thin stand. Oats and wheat were seeded approximately one inch and four inches deep, space planted 8 inches apart each way, and sown on areas one rod square. The test with oats was made in three seasons and involved four varieties, but not all of the varieties were grown every year. The test with wheat was made in one year only and involved two varieties. The total number of plants harvested and the average number of culms per plant produced in the deep and shallow planting for both oats and wheat are shown in Table 26.

TABLE 26.—Depth of Planting in Relation to Tillering—Field Test

Oats				Wheat			
4 in. deep		1 in. deep		4 in. deep		1 in. deep	
Total number of plants	Av. number culms per plant	Total number of plants	Av. number culms per plant	Total number of plants	Av. number culms per plant	Total number of plants	Av. number culms per plant
2644	5.34	3298	6.03	592	8.45	798	8.09

From the average number of culms produced, no clear relationship is indicated between depth of planting and tillering. In both oats and wheat, however, the mortality of seeds was greater in the deep than in the shallow planting. The proportion of seeds from which plants matured in the deep and shallow plantings was 65.6 and 81.8 per cent, respectively, for the oats and 58.7 and 79.2 per cent, respectively, for the wheat.

In a greenhouse test with wheat, conducted in pots in the winter of 1923-24, practically no difference was found in the degree of tillering, but the shallow-planted plants exceeded the deep-planted in length and weight of culms, weight of heads, and weight of threshed grain, Table 27.

TABLE 27.—Depth of Planting in Relation to Tillering—Greenhouse Test

Variety	Manner of planting	Total number of plants	Av. number culms per plant	Length of Culm	Length of Head	Av. weight of Culm	Av. weight of Head	Weight of shelled grain per head
				cm.	cm.	gm.	gm.	gm.
Ohio 15095 Fultz	Deep	94	1.12	82.47	6.99	0.790	0.606	0.379
	Shallow	95	1.10	104.28	7.63	1.557	0.971	0.769
Ohio 13850 D. G. Chaff	Deep	112	1.04	90.76	7.05	1.099	0.943	0.773
	Shallow	118	1.01	100.62	6.71	1.697	1.244	1.006

In both tests—field and greenhouse—no clear relationship was indicated between depth of planting and tillering. Grantham (11) found more tillers in shallow than in deep-planted wheat in three out of four cases.

The depth of root systems was practically the same in both deep and shallow plantings. According to Robbins (42) the permanent roots in grasses always develop near the surface of the ground, regardless of the depth of planting. In neither of these tests was there observed any relationship between depth of planting and lodging. In the greenhouse test the stiff-strawed pure-line strain of Dawson's Golden Chaff stood erect in both plantings while the weak-strawed strain of Fultz lodged in both cases.

Fertilizers.—Certain fertilizers and soil amendments are said to be aids in the prevention of lodging. Potash is often recommended as a remedy for weak straw. Storer (47) states that wheat grown on the saline soil in southern France is less liable to lodge than is that grown on non-saline soils. The effect of these and other substances on the structure of the culms, as reported in the literature, is more or less conflicting. If any of them affect adversely the tillering of the plants, they might be a factor in the prevention of lodging, even though they did not affect materially the composition of the culms.

Tillering tests were made with oats in 1921 to 1923, inclusive, and with wheat in 1922 and 1923. In both cases single seeds were space planted 8 inches apart each way on square-rod areas. Table 28 shows the treatments used and a summary of the results obtained.

TABLE 28.—Fertilizers in Relation to Tillering

Treatment		Oats		Wheat	
Kind	Pounds per acre	Total number of plants	Av. number culms per plant	Total number of plants	Av. number culms per plant
Nothing	....	3134	6.47	1828	10.66
Superphosphate	400	1469	6.06	989	11.87
Muriate of potash	400	1578	7.17	863	11.38
Nitrate of soda	400	1507	6.93	789	10.28
Complete fertilizer	600	1597	7.52	1022	10.90
Limestone	4000	1518	7.00	970	10.52
Salt	400	1489	7.33	867	10.15
Slag	6000	1046	5.60	617	12.63

From these results concerning both oats and wheat, it is difficult to discern a clear relationship between any of the treatments and tillering. Perhaps this is not to be expected from applications made in quantities like these on soils in a high state of fertility.

Late seeding.—Wheat was seeded on different dates through a period of years, the chief object of the experiment being to determine the effect of late seeding on yield. The wheat was sown at the rate of 8 pecks per acre. In a few years the number of culms per acre was estimated, Table 29.

TABLE 29.—Time of Seeding in Relation to Culms per Acre

Year	Date of seeding				
	Sept. 15	Sept. 25	Oct. 5	Oct. 15	Oct. 25
	No.	*No.*	*No.*	*No.*	*No.*
1919	484,000	503,360	580,800	532,400	411,400
1922	1,979,560	1,858,560	1,524,600	1,669,800	1,369,720
1923	2,182,840	2,221,560	1,950,520	1,626,240	1,360,040
1924	2,361,920	2,308,680	1,195,480	740,520	653,400
1925	1,897,280	1,965,040	2,081,200	1,645,600	1,219,680
5-year average	1,781,120	1,771,440	1,466,520	1,242,912	1,002,848

From the table it is apparent that in this latitude seedings made in October result, in most years, in a reduction in stand of plants, and the later the seeding the greater the reduction.

Composition of Culms

From the material already presented, it is clear that a reduction in percentage of dry matter may result from many factors. These may be grouped into two classes (1) soil (Table 6), and (2) climatic (Tables 7 and 8).

SOIL CONDITIONS

So far as the soil is concerned, lodging is always associated with hypernutrition, particularly an abundance of nitrates in the presence of suitable moisture relations. It is, therefore, of importance to consider those field conditions and cultural practices which make for high nitrates on the one hand and for low nitrates on the other, for, as will now be shown, those characterized by high nitrates induce a relatively high proportion of straw, a thick stand, and consequent lodging.

High and low ground.—In depressions, ravines, and on low land in general, as contrasted with more elevated land, there is, with favorable moisture relations, a relatively high nitrate content and this results usually in the development of a high proportion of straw. As has already been mentioned, more total nitrogen was found in typical low than in typical high places of a given field, a contour map of which was shown in Figure 5. A series of determinations showed also a higher nitrate content on the low land when the moisture conditions were favorable.

Table 30 gives the percentage of straw found in oats and wheat on high and low ground.

TABLE 30.—High and Low Ground in Relation to Percentage of Oat and Wheat Straw

Oats		Wheat	
High	Low	High	Low
Per cent 58.95	*Per cent* 65.75	*Per cent* 65.97	*Per cent* 70.58

The number of culms per acre, estimated for a few seasons, was as shown in Table 31.

TABLE 31.—High and Low Ground in Relation to Culms per Acre

Year	Oats		Wheat	
	High	Low	High	Low
	No.	*No.*	*No.*	*No.*
1920	1,340,680	1,592,360	1,539,120	2,681,360
1921	866,360	1,064,800	2,216,720	2,637,800
1922	934,120	1,055,120	2,221,560	2,676,520
1923	1,035,760	1,132,560	2,541,000	2,947,560
1924	831,996	1,290,828	2,528,900	3,217,148
5-year average	1,001,783	1,227,134	2,209,460	2,832,078

On the low land there was an increase in oat and wheat culms of 22.5 and 28.2 per cent, respectively.

Further evidence relative to the development of straw on low land is afforded by referring back to Tables 1, 2, 3, and 4, for in those cases the lodged grain was found on relatively low land and the erect on more elevated soil.

The behavior of small grains grown on high and low ground is illustrated for oats in Figure 27 and for wheat in Figure 28.

In this connection it is of interest to note that the chemical composition of oat and wheat culms taken from high and low ground not only varied, but that the differences were similar to those found in the sand-soil-manure tests; that is, in the culms grown on the low ground there was a marked reduction in total carbohydrates and dry matter, Table 32.

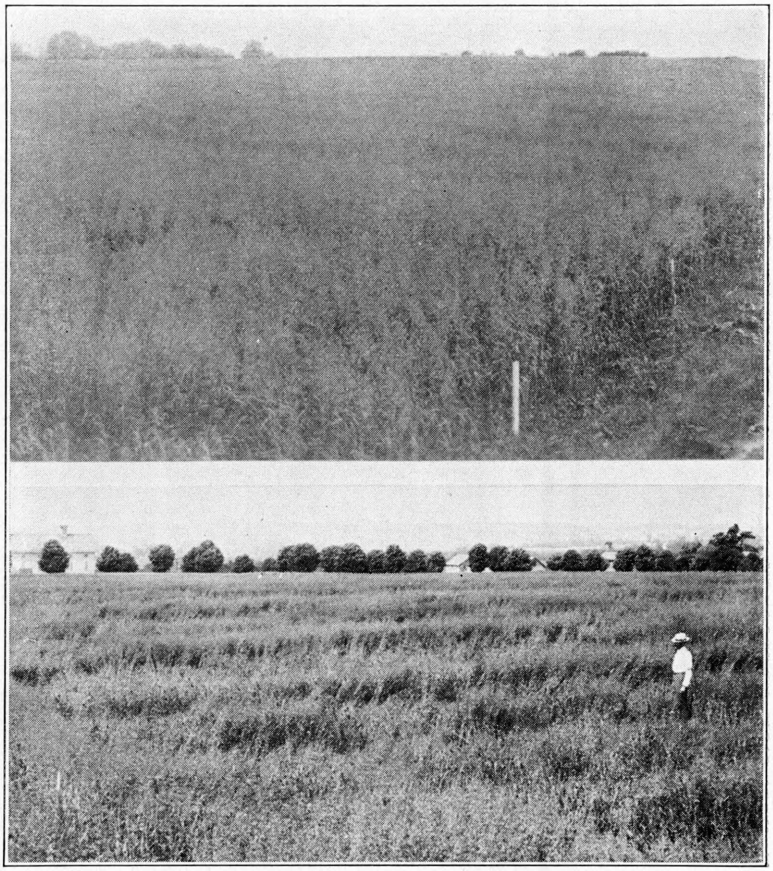

Fig. 27.—Oats grown on high (above) and low ground

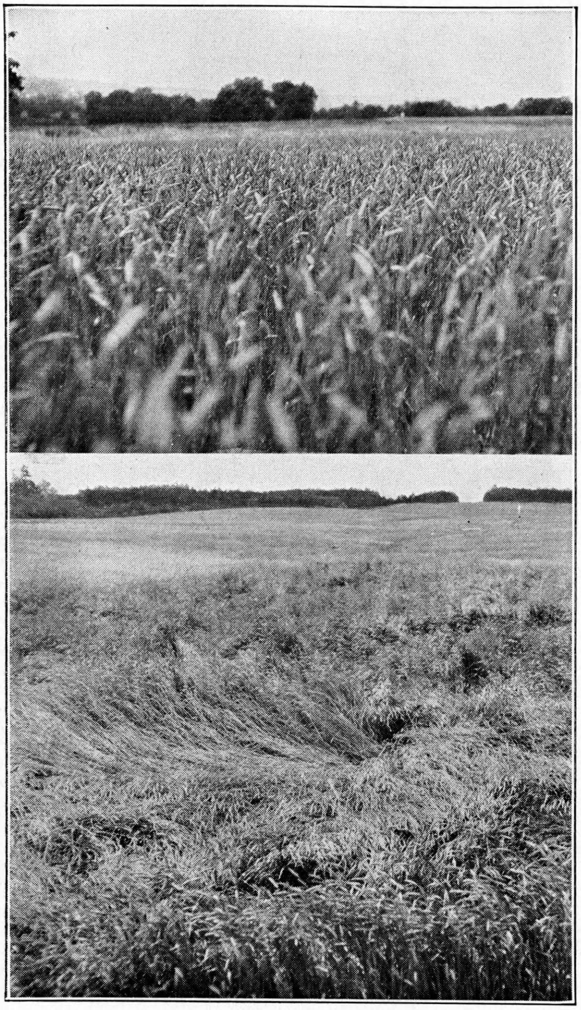

Fig. 28.—Wheat grown on high (above) and low ground

TABLE 32.—**High and Low Ground in Relation to Composition of Oat and Wheat Culms. 1924**

Material	Oats		Wheat	
	High	Low	High	Low
	Per cent	*Per cent*	*Per cent*	*Per cent*
Moisture	68.9	76.4	69.4	78.5
Dry matter	31.1	23.6	30.6	21.5
Total nitrogen	0.068	0.072	0.053	0.082
Free reducing sugars	2.8	1.7	2.1	2.4
Inverted sugars	4.0	0.2	9.9	1.7
Easily hydrolyzable carbohydrates	5.2	3.8	5.5	4.2
Cellulose	3.2	3.7	3.0	3.4
Lignin	10.9	10.2	6.5	6.9
Total carbohydrates	26.1	19.6	27.0	18.6

Calculating the results to unit length per culm, the differences were more pronounced, Table 33.

TABLE 33.—**High and Low Ground in Relation to Constituents per Unit Length of Oat and Wheat Culms. 1924**

Material	Oats		Wheat	
	High	Low	High	Low
	mg.	*mg.*	*mg.*	*mg.*
Moisture	61.5	47.8	44.5	39.7
Dry matter	27.8	14.8	19.6	10.9
Total nitrogen	0.061	0.045	0.034	0.041
Free reducing sugars	2.5	1.1	1.3	1.2
Inverted sugars	3.6	0.1	6.4	0.8
Easily hydrolyzable carbohydrates	4.7	2.4	3.5	2.1
Cellulose	2.9	2.3	1.9	1.7
Lignin	9.7	6.4	4.2	3.5
Total carbohydrates	23.3	12.3	17.3	9.4
Number of culms per 100 gm	32.	34.	60.	52.
Average length of culms, cm	35.	47.	26.	38.
Total length of culms, cm	1120.	1598.	1560.	1976.

Poor and rich soil.—The effect of liberal and long-continued fertilization on lodging is well illustrated by the type of growth made by oats and wheat on the soil—Wooster silt loam—of two of the original farms of the Ohio Agricultural Experiment Station, both of which were acquired at the time of the establishment of the institution at Wooster in 1892. At that time the soil on one farm was in a low state of fertility, it having been in the hands of tenants for a quarter of a century. Since then it has received no manure, fertilizer, or limestone. The present state of fertility is indicated by a 10-year average yield of the crops grown in the 5-year rotation which was in round numbers: corn, 13 bushels; oats, 26 bushels; wheat, 8 bushels; clover, 700 pounds; and timothy, 1300 pounds.

The so-called rich soil was in a good state of fertility and it has been regularly fertilized since. During the last 25 years it has received per acre for each 4-year rotation approximately 10 tons of phosphated manure and 2 tons of limestone on corn and 350 pounds of a so-called complete fertilizer on wheat. The present state of fertility is indicated by the 10-year average yields which, in round numbers, were: corn, 66 bushels; oats, 64 bushels; wheat, 34 bushels; and hay, 3 tons.

Nitrate and moisture determinations were made on these soils in 1921 to 1924, inclusive, and the results are given in Table 34.

TABLE 34.—Poor and Rich Ground in Relation to Nitrates and Moisture

Date of sampling	Nitrates		Moisture	
	Poor ppm.	Rich ppm.	Poor %	Rich %
1921				
May 27	....	....	10.8	19.0
June 8	1.4	5.3	12.4	17.5
June 18	5.0	9.7	11.6	15.4
July 6	6.5	15.3	10.1	13.9
July 16	13.2	21.6	13.4	17.2
July 25	6.2	24.1	10.3	13.7
Aug. 6	10.6	24.3	11.1	14.1
Aug. 10	8.9	26.2	11.0	14.0
Sept. 13	10.8	15.9	13.6	18.1
Sept. 24	10.7	18.3	14.7	18.4
Oct. 6	8.0	15.1	14.9	18.2
Oct. 15	9.2	19.6	14.2	17.2
Oct. 24	8.1	18.7	13.0	16.1
Nov. 3	6.2	17.7	17.3	21.0
Nov. 14	2.1	7.5	18.4	21.9
Nov. 28	1.7	3.9	18.7	21.5
Dec. 10	1.7	3.0	17.3	21.6
Average	6.89	15.39	13.69	17.58
1922				
May 1	2.6	5.9	14.8	18.6
May 8	4.8	9.6	18.1	19.4
May 15	8.6	9.4	19.3	20.5
May 22	4.9	7.0	20.5	21.2
June 12	5.2	3.9	18.0	19.1
June 19	5.4	2.5	15.6	17.1
June 26	5.0	6.9	14.2	14.8
July 7	5.4	7.0	15.7	17.8
July 17	8.0	4.6	13.4	14.7
July 27	3.7	4.8	11.7	12.9
Aug. 14	10.0	6.9	8.6	8.4
Sept. 11	4.4	9.0	11.3	12.7
Sept. 14	3.1	2.7	9.9	10.9
Sept. 29	1.5	11.0	5.0	8.6
Average	5.18	6.51	14.00	15.47
1923				
July 25	19.6	21.9	11.2	12.0
Aug. 1	11.9	11.5	12.0	11.9
Aug. 8	23.5	19.0	15.1	16.9
Sept. 17	14.4	13.4	12.5	14.1
Sept. 27	25.4	21.3	16.1	18.0
Oct. 6	23.5	17.9	15.2	16.1
Oct. 16	22.0	22.3	15.7	15.3
Oct. 26	29.5	36.5	17.2	20.5
Nov. 6	20.7	30.9	17.1	19.8
Nov. 16	19.5	41.4	15.6	19.8
Average	21.00	23.61	14.77	16.44
1924				
May 26	14.2	17.9	17.2	19.8
June 6	3.6	29.2	19.6	20.5
June 16	7.7	18.0	17.5	20.3
June 26	5.1	35.2	16.8	20.5
July 8	5.4	26.5	16.9	19.6
July 18	3.1	25.2	15.1	17.8
July 28	5.4	19.7	12.0	17.5
Aug. 6	3.7	21.6	11.3	15.2
Aug. 16	7.9	39.7	12.0	13.5
Aug. 26	13.7	11.9	11.7	12.0
Average	6.98	24.49	15.01	17.67

In a part of the seasons the quantity of nitrates was considerably higher on the rich than on the poor soil. It is probably differences of this kind that are responsible for a higher average percentage of straw on the more productive land. Based on 10-year average yields, the percentage of straw found on poor and rich soil was 51.4 and 60.5, respectively, for oats, and 61.4 and 66.8, respectively, for wheat.

On the rich soil there was also a greater number of culms per acre, Table 35.

TABLE 35.—Poor and Rich Ground in Relation to Culms per Acre

Year	Oats		Wheat	
	Un-fertilized	Fertilized	Un-fertilized	Fertilized
	No.	*No.*	*No.*	*No.*
1920	1,408,440	1,805,320	....	....
1921	1,466,520	1,592,360	....	....
1922	740,520	1,200,320	1,345,520	1,795,640
1923	755,040	1,408,440	1,718,200	2,323,200
1924	....	....	1,185,800	1,868,240
Average	1,092,630	1,501,610	1,416,507	1,995,693

The effect of high fertility on lodging in small grains is illustrated in Figure 29.

Fig. 29.—Unfertilized (left) and fertilized wheat

Rotations.—The nitrate content of the soil as it goes into oats or wheat is affected by the kind of crops in the rotation. Some of the Station rotations may be used as an example. Soil samples were taken in the fall of 1921 from five different plots, each of which had produced a different crop that summer, although all plots were seeded to wheat in the fall. Each of these plots was a part of a 4-year rotation, the rotations being, (1) corn, oats, wheat, clover; (2) corn, corn, wheat, clover; (3) corn, potatoes, wheat, clover; (4) potatoes, soybeans, wheat, clover; and (5) corn, oats, wheat, clover. The sampling of the plots in these rotations was repeated

TABLE 36.—Rotations in Relation to Nitrates and Moisture

Date of sampling	Nitrates						Moisture					
	Oats ppm.	Wheat ppm.	Clover ppm.	Corn ppm.	Soybeans ppm.	Potatoes ppm.	Oats Pct.	Wheat Pct.	Clover Pct.	Corn Pct.	Soybeans Pct.	Potatoes Pct.
1921												
Sept. 16	7.2	3.1	17.4	8.3	7.7	46.9	14.2	13.7	14.1	15.4	17.9	16.3
Sept. 22	10.4	19.5	22.0	11.4	8.1	40.9	17.2	17.7	17.3	17.9	19.3	16.9
Sept. 28	18.7	21.6	29.1	12.8	12.8	44.4	15.3	15.3	15.2	16.0	18.8	16.4
Oct. 6	14.8	24.1	32.1	14.0	11.9	28.8	16.4	16.6	16.5	17.0	18.6	18.1
Oct. 15	10.4	17.1	25.3	10.4	9.5	25.9	16.5	16.0	16.0	16.5	18.7	17.2
Oct. 24	10.7	15.6	20.8	8.1	8.7	28.8	14.7	14.7	14.4	14.8	16.4	16.4
Nov. 3	13.5	12.6	24.7	9.5	8.2	24.5	20.3	20.2	20.7	20.2	20.2	20.9
Nov. 14	6.7	4.6	13.5	1.2	7.1	16.5	22.2	21.7	22.3	21.2	21.8	21.5
Nov. 28	3.3	3.1	4.0	3.0	4.1	3.3	21.6	22.0	22.0	20.8	20.9	20.7
Dec. 10	1.7	3.0	2.4	2.4	2.6	2.4	20.5	20.7	20.8	20.6	20.3	20.1
Average	9.74	12.4	19.13	8.11	8.07	26.24	17.89	17.86	17.93	18.04	19.29	18.45
1922												
Sept. 16	9.5	11.3	16.7	16.2	4.0	54.6	9.6	10.0	9.5	8.4	8.1	12.9
Sept. 25	11.3	12.9	23.0	10.4	46.4	32.0	7.7	7.1	8.0	6.9	6.2	13.1
Oct. 6	7.9	11.2	16.5	16.7	10.2	27.5	6.7	7.0	6.9	6.4	5.2	8.9
Oct. 16	6.0	13.3	24.5	17.0	3.7	20.0	13.0	13.1	13.0	12.3	12.2	13.9
Oct. 26	8.4	11.8	20.2	6.7	3.2	33.0	11.3	11.9	11.3	11.5	11.4	13.3
Nov. 6	8.5	10.5	30.6	10.5	5.0	32.5	12.7	13.4	12.8	13.3	12.8	13.9
Nov. 16	8.8	11.2	20.2	9.3	3.3	33.0	16.2	15.5	14.5	15.1	15.0	16.2
Nov. 26	9.3	12.5	20.8	8.2	5.8	34.6	12.8	13.5	12.8	12.8	12.7	14.7
Average	8.71	11.84	21.56	11.88	10.20	33.40	11.25	11.44	11.10	10.84	10.45	13.36

TABLE 36.—Rotations in Relation to Nitrates and Moisture—Continued

Date of sampling	Nitrates						Moisture					
	Oats ppm.	Wheat ppm.	Clover ppm.	Corn ppm.	Soybeans ppm.	Potatoes ppm.	Oats Pct.	Wheat Pct.	Clover Pct.	Corn Pct.	Soybeans Pct.	Potatoes Pct.
1923												
Sept. 17	16.5	16.1	17.5	5.5	5.4	11.2	13.0	13.2	14.2	10.7	9.8	12.8
Sept. 27	21.7	16.8	26.1	10.9	4.9	12.0	16.4	17.0	16.8	16.4	14.8	15.6
Oct. 6	17.6	22.9	32.6	9.8	8.8	8.9	14.8	16.0	15.4	14.8	13.2	14.2
Oct. 16	12.3	19.7	23.7	10.0	5.7	10.2	15.0	13.2	14.5	12.9	14.1	14.4
Oct. 26	13.3	24.5	33.6	10.3	5.9	15.9	18.4	18.7	18.8	18.6	17.8	18.7
Nov. 6	10.8	19.8	20.9	9.4	9.0	11.3	18.8	18.9	19.7	18.7	18.5	19.6
Nov. 16	12.2	17.8	31.5	12.1	8.4	9.3	16.9	17.6	17.9	16.5	16.7	17.8
Average	14.91	19.65	26.55	9.71	6.87	11.25	16.18	16.37	16.75	15.51	14.98	16.15
1924												
Sept. 18	25.2	31.1	37.9	12.0	13.8	19.6	19.0	....	16.9	16.3	17.3	17.9
Oct. 6	20.9	25.8	27.1	13.9	12.9	16.2	17.8	15.2	15.4	20.0	16.8	20.3
Oct. 16	17.7	27.0	29.4	12.8	11.1	16.0	17.1	13.7	14.8	16.4	15.8	17.0
Oct. 28	16.6	39.2	28.8	12.6	11.9	37.4	20.2	19.7	19.2	17.6	19.1	18.6
Nov. 6	9.2	16.5	17.0	8.5	6.4	6.2	14.1	15.5	15.7	15.7	16.6	13.9
Nov. 17	4.2	17.1	14.4	6.4	4.3	3.4	14.6	16.1	15.3	15.7	16.5	14.7
Nov. 28	3.0	16.5	14.6	3.8	7.4	3.4	15.8	17.7	16.5	15.6	18.1	16.1
Average	13.82	24.74	24.17	10.00	9.68	14.60	16.94	16.31	16.25	16.75	17.17	16.92

in the three following years. The nitrates and moisture found on these different wheat plots in 1921 to 1924, inclusive, were as shown in Table 36.

The nitrates ran relatively high following clover every year and following potatoes in two years, 1921 and 1922. They ran relatively low every year following corn and soybeans.

The 9-year average percentage of straw (1921-1929, inclusive) produced by the wheat grown after the various crops was as follows: corn, 57.4; soybeans, 57.9; potatoes, 58.4; oats, 57.2; and clover, 62.5.

In general, the percentage of straw follows the nitrate content of the soil, it being highest in the wheat following clover and next highest in that following potatoes.

In three seasons the number of culms per acre was estimated, and the results were as shown in Table 37.

TABLE 37.—Rotations in Relation to Wheat Culms per Acre

Year	Crop preceding wheat				
	Corn	Soybeans	Potatoes	Oats	Clover
	No.	*No.*	*No.*	*No.*	*No.*
1922	1,810,160	1,612,040	1,635,920	1,839,200	2,507,120
1923	2,013,440	1,887,600	2,613,600	1,989,240	2,361,920
1924	1,994,080	1,534,280	1,669,800	1,998,920	1,965,040
3-year average	1,939,227	1,677,973	1,973,106	1,942,453	2,278,026

The number of culms per acre was also correlated in general with the nitrate content of the soil, it being highest in the wheat following clover and second highest in that following potatoes.

If more than one year in a rotation is devoted to a legume like alfalfa, the small grain crop often lodges as illustrated in Figure 30.

Manner of preparation of seedbed.—The nitrate content of the soil may be affected by the way in which the seedbed is prepared. An oat test at the Ohio Station will serve as an example. In this 18-year test one plot was sown early without any previous preparation of seedbed. This is not an uncommon practice in some sections of the State. In two other cases seeding was deferred until the ground was dry enough to work, and then the ground for one plot was disked; for the other, plowed. Corn was the preceding crop. In four seasons an extension of each of these three plots was left fallow. From this fallow ground soil samples were taken from time to time during the growing season, and upon these nitrate and moisture determinations were made as shown in Table 38.

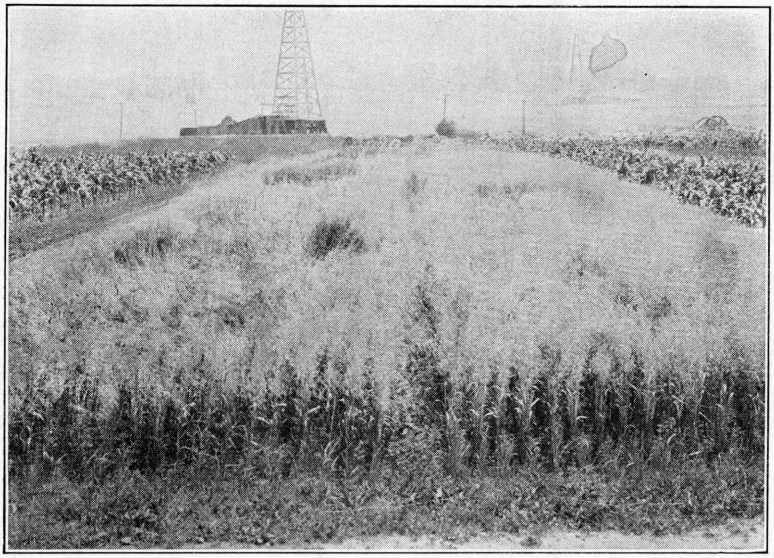

Fig. 30.—Both of these plots of oats were seeded on corn stubble ground but each was a part of a different 5-year rotation. The rotations were (left) corn, oats, alfalfa, alfalfa, and alfalfa; (right) corn, oats, corn, wheat, and clover.

As compared with the unstirred ground, the plowed plots contained a much larger quantity of nitrates in two seasons, 1921-1922, and in one season, 1922, it contained approximately twice as much as the disked. Lyon, Bizzell, and Conn (28) found more nitrates in aerated than in unaerated soil.

The proportion of straw is not given, for the records are not regarded as reliable for this purpose because in many years, particularly wet ones, not only much of the straw on the plowed plot was lost through lodging, but the weight of straw on the unprepared seedbed was unduly increased by weeds.

In this test the number of culms per acre as estimated in four seasons is given in Table 39.

The number of culms per acre was markedly higher on the disked and plowed, than on the unprepared land, and somewhat higher on the plowed, than on the disked land. Aside from the more favorable soil conditions on the plowed and disked plots as contrasted with the unprepared plot, the big reduction in stand is due to a large mortality of seeds. Exposed to freezing and thawing on the surface of the ground, many failed to germinate, and others, no doubt, were carried away by birds. The thin stand resulted in the development of large, strong, stiff culms which

TABLE 38.—Seedbed in Relation to Nitrates and Moisture

Date of sampling	Nitrates			Moisture		
	No prep. ppm.	Disked ppm.	Plowed ppm.	No prep. Pct.	Disked Pct.	Plowed Pct.
1921						
May 27	....	....	....	18.4	19.1	24.8
June 8	0.4	6.7	6.9	13.6	16.5	16.0
June 18	4.4	6.8	8.6	12.7	14.4	15.8
July 6	9.4	11.6	12.7	11.8	14.8	14.4
July 16	14.2	21.2	27.3	16.9	17.3	18.5
July 25	11.7	16.0	17.0	12.9	14.5	15.5
Aug. 6	12.3	33.7	26.5	13.8	15.7	16.0
Aug. 10	12.4	15.6	26.1	13.3	14.6	15.5
Average	9.26	15.94	17.87	14.17	15.86	17.06
1922						
May 1	1.9	3.0	7.0	19.7	17.5	19.1
May 8	2.8	6.1	9.9	20.4	19.8	20.3
May 15	2.4	4.5	11.2	21.5	19.9	20.7
May 22	1.5	3.1	3.4	22.4	21.2	21.7
June 12	4.3	5.4	8.5	19.1	17.6	17.7
June 19	3.6	3.7	7.0	16.2	14.5	14.8
June 26	4.0	4.2	4.7	14.4	13.0	13.3
July 7	7.3	9.7	12.4	17.6	15.9	16.7
July 17	7.7	10.1	11.7	13.8	13.9	13.1
July 27	4.8	5.5	10.4	12.0	12.2	12.4
Aug. 14	8.9	5.0	24.6	8.1	7.9	9.1
Average	4.47	5.48	10.07	16.83	15.76	16.26
1923						
May 26	23.0	24.6	13.1	14.5	12.9	14.3
June 13	19.7	14.1	13.6	14.7	14.5	15.3
June 26	23.3	41.6	19.2	7.8	7.2	9.9
July 10	20.6	27.2	26.2	8.3	7.8	9.1
July 25	15.5	13.8	21.0	12.0	11.5	12.9
Aug. 1	22.6	19.7	19.7	12.2	12.7	12.8
Aug. 8	30.5	37.5	49.3	16.0	14.9	15.6
Aug. 15	35.5	37.0	32.0	15.2	14.5	14.5
Average	23.83	26.93	24.26	12.59	12.00	13.05
1924						
May 26	16.0	....	15.6	18.6	19.5	20.7
June 6	13.0	17.3	16.5	19.5	20.7	21.0
June 16	9.8	13.0	10.5	19.0	19.7	21.1
June 26	6.9	13.3	14.5	17.7	18.5	21.0
July 8	6.7	4.3	3.2	18.2	18.4	20.2
July 18	3.5	3.5	5.9	15.3	15.0	17.2
July 28	6.7	4.9	6.8	15.7	13.7	15.2
Aug. 6	3.8	4.7	7.0	13.9	13.0	14.3
Aug. 16	7.4	6.9	8.5	13.5	12.7	13.7
Average	8.20	8.48	9.83	16.82	16.80	18.27

TABLE 39.—Seedbed in Relation to Culms per Acre

Year	No preparation	Disked	Plowed
	No.	*No.*	*No.*
1921	464,640	1,006,720	1,026,080
1922	469,480	856,680	948,640
1923	329,120	745,360	803,440
1924	755,040	774,400	871,200
4-year average	504,570	845,790	912,340

rarely lodge. On the disked plot, and particularly on the plowed one, the stand was thicker, the culms smaller, and more inclined to lodge. Between the unprepared and plowed plots the difference in lodging was often very marked as shown in Figure 31.

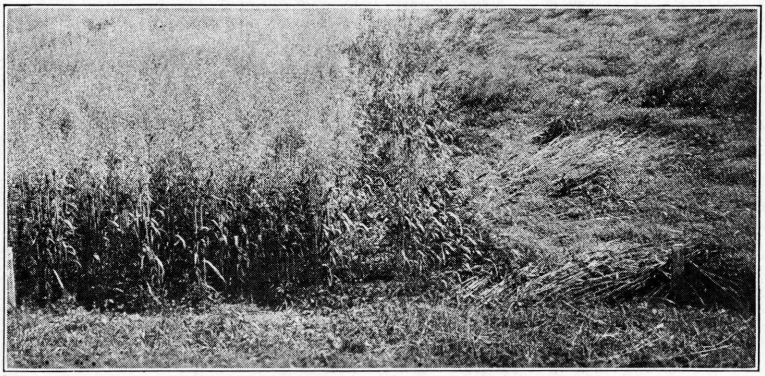

Fig. 31.—Oat ground unprepared (left) and plowed

The erectness of straw, however, was obtained at a considerable sacrifice in production; the 18-year average yield on the unprepared, disked, and plowed plots being 45.7, 55.2, and 55.8 bushels, respectively

CLIMATIC CONDITIONS

The differences in lodging noted from year to year probably result from seasonal variations in climatic factors, for temperature, sunshine, and rainfall (through soil moisture relations) have been shown to affect the composition of the culms. That there is an appreciable seasonal variation in these climatic factors is shown by the weather records of the Ohio Station.

Temperature.—The variation in mean temperature for the months of March, April, May, June, and July during the last 41 years is shown in Table 40.

TABLE 40.—Mean Temperature, by Months and Years, at Wooster

Year	March	April	May	June	July
1888	31.7	46.3	57.7	66.0	70.1
1889	38.7	47.1	57.8	64.5	70.0
1890	30.9	48.4	56.0	69.8	70.5
1891	32.0	49.0	55.0	68.0	67.5
1892	33.2	47.1	57.3	70.5	69.6
1893	37.7	50.1	57.6	71.2	74.3
1894	43.5	50.5	57.5	67.9	71.4
1895	32.4	49.5	59.4	69.9	68.6
1896	29.8	54.6	64.5	65.6	70.2
1897	39.8	47.4	53.4	64.4	73.2
1898	43.3	45.3	58.2	68.7	74.5
1899	35.0	52.1	60.0	69.3	71.1
1900	31.7	47.8	61.5	68.4	72.6
1901	39.0	45.2	58.0	69.1	76.0
1902	41.3	46.2	61.4	65.6	73.0
1903	45.7	48.6	62.2	63.0	71.8
1904	37.6	42.8	59.4	67.0	69.8
1905	41.2	46.8	59.2	68.0	71.6
1906	30.2	51.9	59.9	68.8	71.0
1907	44.9	41.7	52.8	64.6	69.9
1908	43.1	50.0	62.2	68.1	72.4
1909	35.9	48.4	57.9	69.3	69.6
1910	47.2	50.2	54.8	64.1	72.6
1911	35.0	46.4	63.6	68.9	71.8
1912	30.4	50.0	61.2	64.6	71.6
1913	38.5	48.9	57.9	67.4	72.4
1914	34.2	48.4	59.8	68.4	71.0
1915	31.2	53.2	55.6	64.6	69.2
1916	32.0	46.8	60.2	62.9	74.6
1917	36.3	47.8	52.6	66.3	71.8
1918	43.1	48.6	65.0	67.3	70.4
1919	39.7	48.7	58.1	73.2	73.7
1920	41.6	44.4	56.4	67.4	69.1
1921	48.0	55.2	60.6	71.0	76.2
1922	41.2	51.2	62.2	69.2	71.3
1923	36.8	47.3	56.9	69.6	71.7
1924	35.1	48.3	54.5	66.6	68.8
1925	40.2	52.0	53.6	72.0	70.4
1926	32.6	43.0	58.0	64.4	71.4
1927	41.4	49.1	59.0	62.8	71.0
1928	36.9	45.7	57.4	64.1	72.7
Average	37.6	48.3	58.4	67.4	71.5

The difference between the extremes for each month were 18.2° in March (48.0° in 1921—29.8° in 1896); 13.5° in April (55.2° in 1921—41.7° in 1907); 12.4° in May (65.0° in 1918—52.6° in 1917); 10.4° in June (73.2° in 1919—62.8° in 1927), and 8.7° in July (76.2° in 1921—67.5° in 1891).

Sunshine.—The hours of sunshine for the months of March, April, May, June, and July as measured by an automatic sunshine recorder during the last seven years (1923-1929, inclusive) are recorded in Table 41.

From the table it is clear that there is a marked difference in the hours of sunshine in a given month in different years. Conobtained by dividing the total yield into the weight of straw. The sidering the total number of hours in the five months, the lowest was 1038 hours in 1925, and the highest was 1257 hours in 1928, an increase of the latter over the former of 21.1 per cent.

TABLE 41.—Hours of Sunshine per Month

Year	March	April	May	June	July	Total
1923	121.25	223.30	285.50	307.10	299.00	1236.15
1924	124.50	195.80	204.67	253.80	314.17	1092.94
1925	151.50	212.70	197.10	250.80	226.33	1038.43
1926	157.60	199.80	289.20	296.70	305.33	1248.63
1927	129.05	197.90	195.20	258.70	289.33	1070.18
1928	175.60	185.70	306.40	252.90	336.33	1256.93
1929	165.00	201.50	277.70	198.80	234.25	1077.25
7-year average	146.36	202.38	250.83	259.83	286.39	....

Cloudiness affects the intensity of light, and a reduction in intensity, such as is caused by a single layer of cheesecloth, is sufficient, as has already been shown, to induce lodging. As measured by a slight modification of Ridgway's chemical photometer (40), the intensity of the light, after having passed through the cheesecloth in question, was approximately 50 per cent of that in the open. Measured by the same method, the intensity of light on a day entirely cloudy was found to be 26.5 per cent of the intensity on a clear sunshiny day.

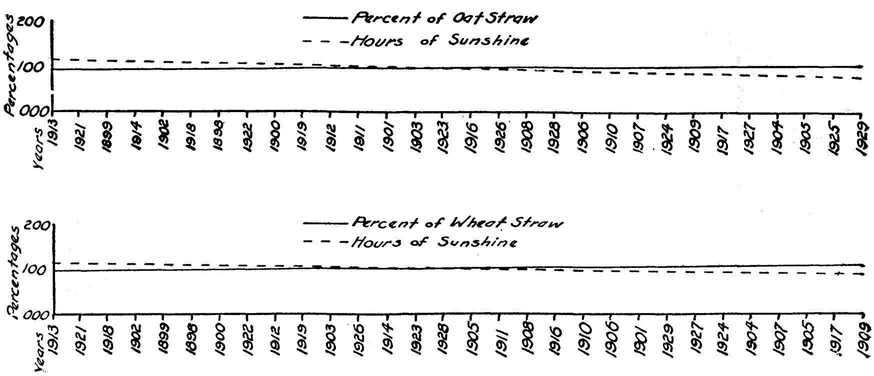

Fig. 32.—Graphs of oat and wheat straw and sunshine, expressed in percentages of their respective means. 30-year records

That a relationship exists between cloudiness and the character of growth made by oats and wheat is indicated in Figure 32. In constructing the straight lines the sunshine records used for each year represent the total for the months of April, May, June, and July in the case of the oats, and for the months of March, April, May, and June in the case of wheat. The percentage of straw was per cent of straw value and the rainfall value for any given year were then plotted on the same ordinate and the years were arranged in the order of decreasing sunshine. After plotting the figures for percentage of straw and for sunshine, there was fitted into each set of values a straight line by the method of least squares. The straight lines only are shown in the accompanying figures, and from these the conclusion may be drawn that with decrease in sunshine there is an increase in per cent of straw developed in both oats and wheat. The effect of partial shade each day is illustrated in Figure 33.

Fig. 33.—Both views of wheat were taken from the same spot in a given field. The lower one was shaded a part of each day by the adjoining trees

Rainfall.—The inches of rainfall in the oat and wheat growing period, that is, for the months of March, April, May, June, and July, during the last 41 years were as shown in Table 42. Considering the total rainfall for the five months, the extremes in the 41 years were 11.44 inches (1895) and 26.13 inches (1892).

TABLE 42.—Precipitation, by Months and Years, at Wooster—Inches

Year	March	April	May	June	July	Total
1888	3.34	2.48	3.82	2.31	4.54	16.39
1889	2.13	1.58	2.97	4.86	6.73	18.27
1890	4.37	3.10	6.37	4.92	2.67	21.43
1891	3.71	1.66	2.24	7.13	3.24	17.98
1892	3.38	2.44	7.69	7.89	4.73	26.13
1893	1.89	5.66	6.28	2.51	1.38	17.72
1894	2.36	1.74	4.41	2.23	1.38	12.12
1895	1.98	1.69	1.38	4.20	2.19	11.44
1896	3.67	3.34	3.41	3.98	8.05	22.45
1897	2.81	2.75	4.97	2.98	3.89	17.40
1898	6.44	2.56	4.60	2.70	6.79	23.09
1899	3.95	1.28	4.42	1.95	3.73	15.33
1900	2.25	1.70	2.23	3.71	5.65	15.54
1901	3.09	2.46	4.32	4.82	3.32	18.01
1902	2.99	1.55	2.57	5.55	5.26	17.92
1903	3.29	4.55	1.59	3.69	4.61	17.73
1904	6.22	6.59	4.45	1.67	4.93	23.86
1905	2.61	2.51	5.97	7.50	5.14	23.73
1906	3.57	2.27	2.98	3.81	4.93	17.56
1907	5.80	2.69	3.48	3.81	3.96	19.74
1908	5.02	3.64	4.56	2.17	3.44	18.83
1909	3.02	3.92	4.06	6.44	4.05	21.49
1910	.54	3.22	4.87	2.57	1.12	12.32
1911	3.26	3.71	2.45	3.78	3.36	16.56
1912	3.77	5.58	5.65	2.21	7.46	24.67
1913	11.84	3.66	3.04	.97	4.07	23.58
1914	2.37	4.33	2.98	6.33	1.23	17.24
1915	1.17	1.41	2.80	6.32	8.35	20.05
1916	4.72	2.92	2.95	5.05	2.21	17.85
1917	3.66	2.00	3.94	4.84	2.20	16.64
1918	2.01	2.96	4.88	1.91	2.68	14.44
1919	3.82	2.66	6.17	2.62	6.42	21.69
1920	2.08	5.67	1.59	8.26	3.67	21.27
1921	6.26	4.28	3.42	2.77	2.92	19.65
1922	3.80	4.39	5.61	3.04	5.04	21.88
1923	2.49	2.28	4.11	1.99	2.08	12.95
1924	2.82	2.86	4.13	6.40	4.32	20.53
1925	2.50	1.87	2.35	2.24	4.09	13.05
1926	1.87	2.52	2.63	3.58	2.49	13.26
1927	4.11	3.02	4.45	3.36	4.28	19.22
1928	3.52	2.67	1.69	5.17	3.75	16.80
1929	3.18	5.58	4.84	4.10	6.79	24.49
Average	3.52	3.03	3.86	4.00	4.06	18.47

That rainfall is an important factor in lodging is shown by the behavior of oats and wheat grown on liberally fertilized plots on the Station farm in comparatively wet and dry years. For example, in a 4-year rotation of corn, oats, wheat, and clover, in which a certain plot receives per acre per rotation 8 tons of manure and 480 pounds of superphosphate (16%), all of which is applied to the corn, the oats following lodged badly in the wet season, 1920, but stood perfectly erect in the dry season, 1925. The difference is illustrated in Figure 34.

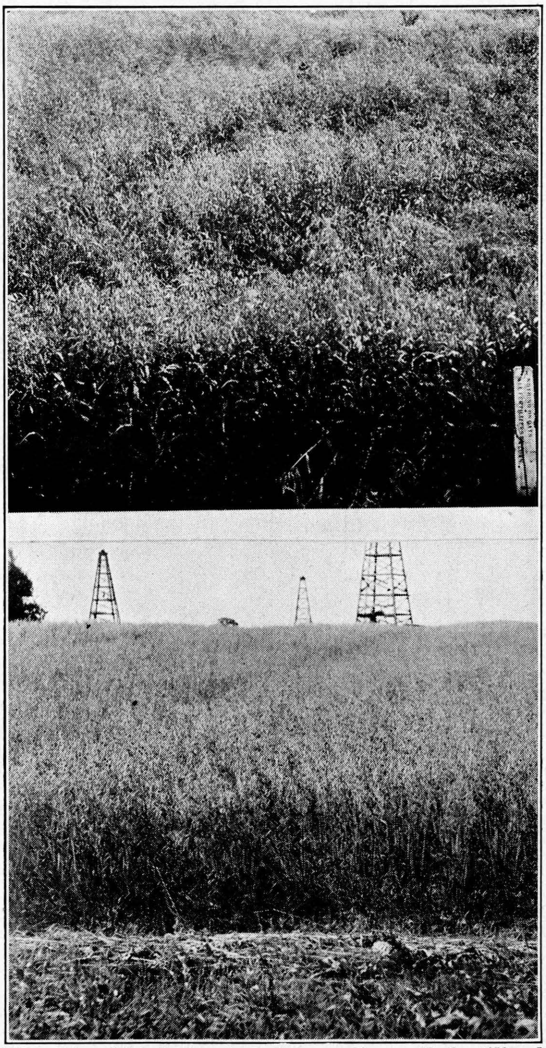

Fig. 34.—The behavior of oats on well fertilized land in wet (above) and dry seasons

Since lodging is associated with high moisture content of the culms, and since the latter varies within limits with soil moisture, it is to be expected that lodging would be more prevalent in wet than in dry years. The rainfall for the months of March, April, May, and June 1920 was 17.60 inches and for the same months in 1925, 8.96 inches.

Whenever environmental conditions, including an abundance of rainfall, have been such as to create a critical condition in oats or wheat from the standpoint of lodging, then a moderate increase in rainfall may make the difference between lodging and non-lodging. A peculiar and very striking case of lodging, apparently due to such a situation, occurred in the variety range of wheat on the Station farm in 1919. The range consists of 90 one-tenth acre plots; each plot is 16 feet wide. They had recently been plowed the long way east and west, making a back furrow lengthwise. Eighty-one of these plots were seeded to different varieties of wheat. On the night of June 8, 0.58 inch of rain fell. There was no wind. Out of the eighty-one plots the wheat on 60 of them lodged, chiefly on the north side only. Of course, the line of demarcation was not absolute, but, in general, the lodging was confined to the north side. A part of the remaining plots lodged entirely, and a part of the so-called stiff-strawed ones remained entirely erect. A typical condition of the situation which prevailed on the partially lodged plots on June 14, six days after the rain, is illustrated in Figure 35.

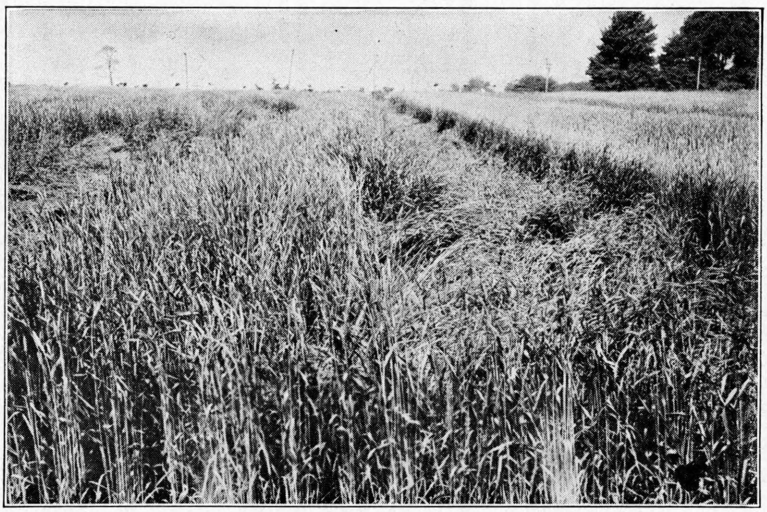

Fig. 35.—Wheat lodged on north side only of ridged plot

On the north and south sides of one of the plots of the non-lodged, stiff-strawed varieties the moisture content of the soil was determined. The surface samples of soil were taken to a depth of 7 inches; the subsoil to a depth of 3 feet. There was a difference in moisture content of 0.68 per cent in the surface soil and of 1.94 per cent in the subsoil; the higher amount in both cases being on the north side, the side sloping from the sun.

An examination of the moisture content of culms gathered from the north and south sides of this same plot and of those selected in a similar manner from a second stiff-strawed, non-lodged variety showed a difference of 1.87 per cent in the case of the Dawson's Golden Chaff variety and of 1.19 per cent in the case of the Prosperity. In both instances the higher moisture content was found on the north side of the plots. Of course, these differences in moisture are very small, but the writers have no other suggestions to offer by way of explanation of a condition sufficiently marked to attract the attention and to provoke comment by all the farm hands who chanced to observe the varieties at this particular time. Occasionally the difference in moisture content between the north and south sides of newly ridged plots is observable to the eye as is illustrated in Figure 36. In this case the difference in moisture content of the surface soil was 1.14 per cent, that of the north side being higher.

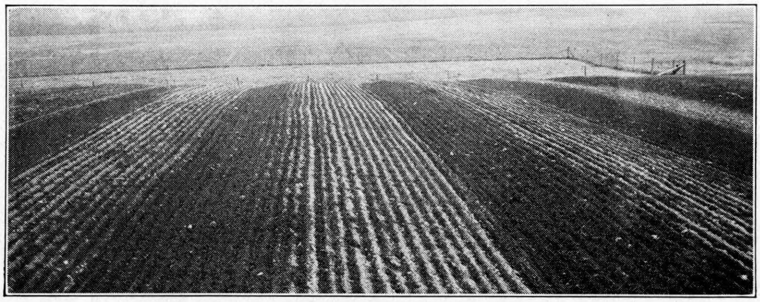

Fig. 36.—Relative moisture on north and south sides of ridged plot

On the other hand, excessive rains alone do not cause lodging on poor ground. This is well illustrated in Figure 37. Prior to the beginning of the experiment in 1893, this land had been in the hands of tenants and was very poor. In the first five of the thirty-five years during which it has been under experiment, the average yield was 26.3 bushels of corn, 28.2 bushels of oats, and 10.1 bushels of wheat. The plot shown in the lower part of this figure has received no fertilization of any kind in the last 35 years and is now yielding approximately 9.1 bushels of corn, 14.1 bushels of oats, and 7.2 bushels of wheat. The plot shown in the upper part of the figure has been systematically treated for the last 35 years with commercial fertilizers and is now yielding approximately 38.7 bushels of corn, 38.3 bushels of oats, and 22.4 bushels of wheat. The oats were grown in 1920, and, as has already been mentioned, that was a season of heavy rainfall.

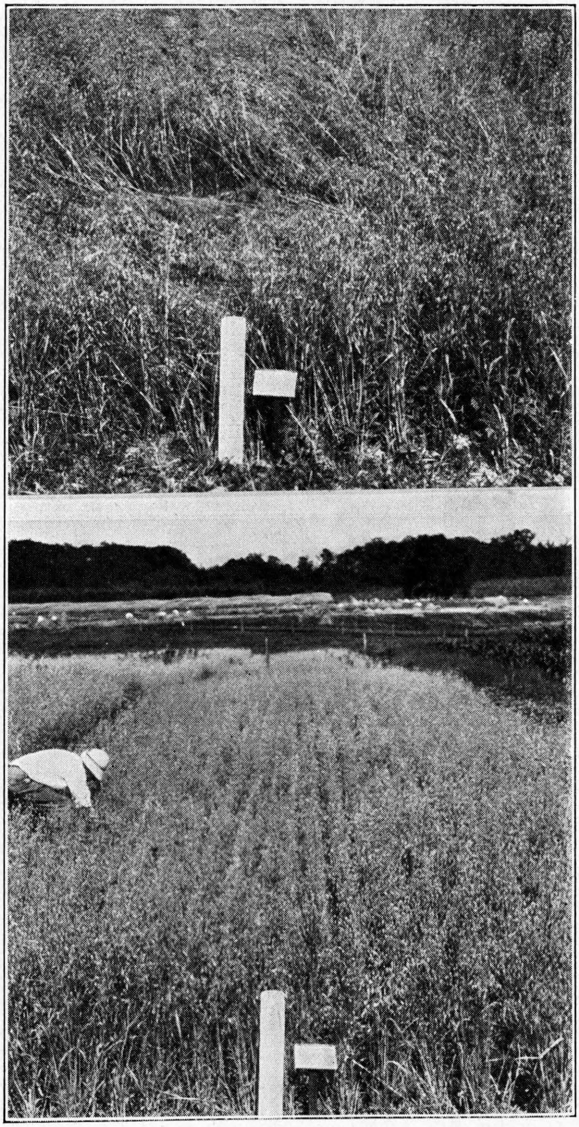

Fig. 37.—Behavior of oats in a wet season on well fertilizer ground (above) and on poor soil (below)

Aside from the effect of high soil-moisture content on the composition of the culms, the extra load imposed by the weight of the water which rests on the leaves and clings to the stems is often considerable. After oats are in full head, but before the leaves begin to wither, the quantity of water able to adhere to the leaves and culm may equal approximately one-fifth of their own green weight. This estimate is based on the amount of water found on 100 culms each of six midseason varieties, Storm King, Ohio 201, Victory, Silvermine, Wideawake, and Alaska. The determinations were made on the morning of July 9, 1921, while the field was enveloped with heavy, low-hanging clouds following a rainfall of 0.65 inch the preceding night. Of course, the taller the oats, the greater would be the load and the further removed would be a part of it from the base of support. Carleton (4) mentions tallness as one factor in lodging.

The variations in rainfall from year to year affect not only the soil moisture, but also, no doubt, the development of nitrates. That the nitrate and moisture content of adjoining soils uniformly fertilized vary from season to season is shown by series of determinations made in 1922, 1923, and 1924, the results of which are shown in Table 43.

TABLE 43.—Seasons in Relation to Nitrates and Moisture

Date	Nitrates			Moisture		
	1922	1923	1924	1922	1923	1924
	ppm.	*ppm.*	*ppm.*	*Pct.*	*Pct.*	*Pct.*
May 8	9.6	......	......	20.0	......	......
May 15	17.1	......	......	20.6	......	......
May 22-26	14.4	13.4	15.7	22.3	16.5	18.2
June 6	......	......	22.8	......	......	21.5
June 12-13	46.2	35.2	......	18.6	18.0	......
June 16-19	37.5	......	24.6	17.7	......	21.0
June 26	28.6	41.6	28.2	16.9	12.4	19.4
July 7-10	43.2	36.0	27.3	18.4	13.6	19.4
July 17-18	41.8	......	22.3	17.1	......	17.5
July 24-25	42.7	28.4	......	16.4	13.5	......
July 28-Aug. 1	33.8	28.6	16.2	14.7	12.0	14.4
Aug. 6-8	24.8	37.7	13.3	14.3	17.1	13.3
Aug. 14-16	38.1	20.4	11.9	13.4	14.9	12.9
Aug. 21	62.5	......	......	13.2	......	......
Aug. 26-28	75.0	25.5	29.9	14.0	10.8	13.4
Sept. 4-8	71.3	19.3	21.2	14.6	12.2	11.8
Sept. 11	75.5	......	......	16.8	......	......
Sept. 17-18	60.2	17.6	24.6	13.4	11.8	18.0
Sept. 25-27	43.8	12.9	......	12.6	14.9	......
Oct. 6	39.2	12.5	20.9	10.7	13.8	16.2
Oct. 16	48.7	16.6	19.6	15.5	14.3	16.0
Oct. 26-28	50.1	15.7	13.7	13.3	18.0	15.4
Nov. 6	59.0	16.4	24.6	15.8	18.2	19.3
Nov. 16-17	58.4	15.5	14.6	17.4	16.6	14.8
Nov. 26-28	54.7	......	20.6	14.7	......	16.3
Average	44.84	23.13	20.66	15.93	14.62	16.60

In one season, 1922, the nitrates were practically twice as high as in the other two years.

Proportion of straw.—As a result of the inter-action of all environmental factors—cultural, soil, and climatic—there was a marked variation in the character of growth made by oats and wheat from season to season. Table 44 shows the percentage of straw in a single variety each of oats and wheat in 30 different seasons.

TABLE 44.—Seasons in Relation to Percentage of Straw

Year	Oats*				Wheat*			
	Grain	Straw	Total	Straw	Grain	Straw	Total	Straw
	Bu.	*Lb.*	*Lb.*	*Pct.*	*Bu.*	*Lb.*	*Lb.*	*Pct.*
1898	45.01	2146	3586.3	59.84	18.50	2494	3604.0	69.20
1899	53.18	1812	3513.7	51.56	28.55	1987	3700.0	53.70
1900	46.57	1484	2974.2	49.89	11.16	1566	2235.6	70.04
1901	44.99	1854	3293.7	56.28	15.17	2074	2984.2	69.50
1902	77.26	1800	4272.3	42.13	22.86	2022	3393.6	59.58
1903	44.43	1703	3124.7	54.50	33.39	2926	4929.4	59.36
1904	77.26	3120	5592.3	55.80	24.88	2495	3987.8	62.56
1905	56.65	3131	4943.8	63.33	17.81	1948	3016.6	64.58
1906	73.02	3619	5955.6	60.76	43.78	4075	6701.8	60.80
1907	40.20	3017	4303.4	70.11	24.06	3308	4751.6	69.62
1908	50.19	3397	5003.0	67.90	41.47	3968	6456.2	61.42
1909	55.42	4028	5801.4	69.43	35.28	4785	6901.8	69.33
1910	61.76	6020	7996.3	75.28	28.10	3611	5297.0	68.17
1911	56.16	2566	4363.1	58.81	29.59	2840	4615.4	61.53
1912	73.74	3602	5961.6	60.42	16.50	2111	3101.0	68.07
1913	37.16	1431	2620.1	54.61	29.55	4092	5865.0	69.77
1914	59.92	3911	5828.4	67.10	35.38	3872	5994.8	64.59
1915	....	....	....	....	33.41	4461	6465.6	68.99
1916	52.21	3911	5581.7	70.07	32.78	3451	5417.8	63.70
1917	66.23	4274	6393.3	66.85	42.88	3660	6232.8	58.72
1918	89.82	3842	6716.2	57.20	36.54	3121	5313.4	58.74
1919	37.70	3098	4304.4	71.97	30.47	4542	6370.2	71.30
1920	61.96	....	....	....	18.22	....	....	....
1921	49.32	2627	4205.2	62.47	26.58	3581	5175.8	69.19
1922	49.17	3583	5156.4	69.48	25.27	4031	5547.2	72.67
1923	57.96	3245	5099.7	63.63	43.15	3968	6557.0	60.52
1924	75.98	5467	7898.3	69.22	29.84	4741	6531.4	72.60
1925	57.08	1703	3529.5	48.25	....	....	....	....
1926	88.00	2646	5462.0	48.44	40.92	3510	5965.2	58.84
1927	88.79	3538	6379.2	55.46	40.41	5180	7604.6	68.12
1928	59.11	1832	3723.5	49.20	31.36	3430	5311.6	64.57
1929	49.18	1679	3252.7	51.62	34.80	4376	6464.0	67.70

*The yields represent the average of approximately 30 tenth-acre plots.

Between the extreme percentages there was a difference of 33.15 in oat straw and 18.97 in wheat straw. Since the oats and wheat were grown year after year in regular rotation on four ranges of land lying side by side and were treated, in all essential particulars, the same for over 30 years, the variations must have been due chiefly to climatic differences.

The relation of character of growth in oats and wheat to rainfall is shown in Figure 38. The straight lines were constructed in the same manner as were those in connection with sunshine. The rainfall used was the total for the months of March, April, May, June, and July for the oats and for the same months, exclusive of July, for the wheat. The years were arranged in the order of decreasing rainfall. The straight lines only are shown in the accompanying figures and from these the conclusion may be drawn that with increase in rainfall there is an increase in per cent of straw developed in both oats and wheat. These results are in accord with the findings of Mayer (30) and Widtsoe (54).

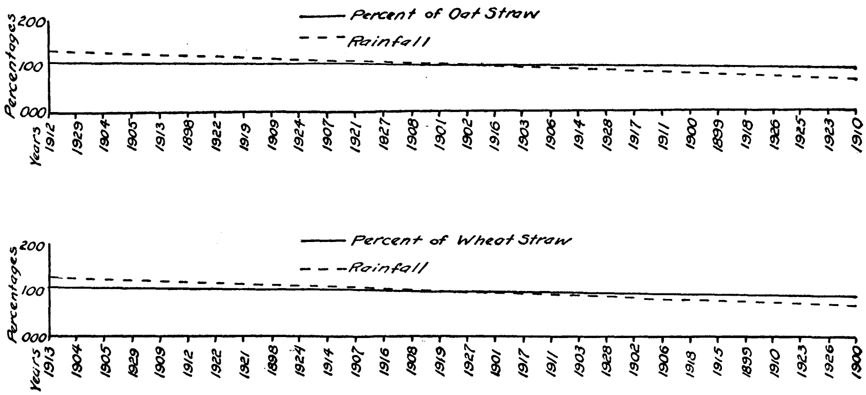

Fig. 38.—Graphs of oat and wheat straw and rainfall, expressed in percentages of their respective means. 30-year records

Estimated number of culms per acre.—In five seasons there was calculated the number of culms per acre, based on the average stand of ten or more varieties, Table 45.

TABLE 45.—Seasons in Relation to Culms per Acre

Year	Oats	Wheat
	No.	*No.*
1920	1,804,352	857,648
1921	1,590,424	1,711,424
1922	1,245,332	1,820,324
1923	1,405,536	2,319,812
1924	991,232	1,868,240
5-year average	1,407,375	1,715,490

From the table it may be seen that the number of culms per acre tends to run quite uniform from year to year, but in some seasons there were marked exceptions. Between the extremes there was a variation of 82.0 per cent in oats and 170.5 per cent in wheat. Of the five years concerned, 1924 was the most favorable for the growth of oats, it being cool and wet. Each plant grew strong and vigorous and, although the stand was comparatively thin, the yield produced was the highest in the five-year period. This is of interest because it shows that with favorable environmental conditions a good yield may be obtained with a thin stand, and the latter is desirable from the standpoint of lodging.

The yield of wheat was highest in 1923 and lowest in 1920. The extremely thin stand in the latter year was due to winter-killing.

In some seasons oats and wheat, even on very fertile ground, remain perfectly erect until harvest. In other years they lodge badly. A common variation due to seasons is illustrated in Figure 34.

REMEDIAL MEASURES

Control of lodging is extremely difficult because a part of the environmental factors from which it results are climatic and over these the farmer, of course, has no control. Much, however, may be done to alleviate the situation through choice of seed and through the handling of the soil.

SEED

Preference should be given to varieties and strains of low tillering capacity, for these produce relatively large, coarse, stiff culms. The grain should be well cleaned to remove, as far as possible, the smaller kernels, and it should be sown thinly. In the most productive fields on the Station farm the seeding of low tillering varieties at the rate of 4 or 5 pecks per acre has rarely given any trouble from lodging, except as a result of violent storms. In the case of wheat, late seeding is advantageous, for that tends to insure a thin stand.

Clipping.—The cutting off of oats and wheat before the culms begin to elongate appreciably, helps to prevent lodging because it makes for a thin stand, and a slight reduction in height of culms. It is likely also to reduce the yield. In 1924 clipping square-yard areas of wheat the middle of April to a height of 4 inches reduced the stand 15.4 per cent, the height of plants 0.7 per cent, and the yield 13.3 per cent. Clipping to a height of 2½ inches reduced the stand 25 per cent, the height 6.7 per cent, and the yield 29.3 per cent. In a second test made in 1925 clipping wheat to a height of 4 inches reduced the stand 18.9 per cent, the height 20.1 per cent, and the yield 50.3 per cent. The effectiveness of the clipping varies with the lateness of the season. In 1924 clipping wheat to a height of 4 inches reduced the height of culms 2.3 per cent when cut April

19, 3.3 per cent when cut April 29, and 23.3 per cent when cut May 9. It reduced the number of culms 9.8 per cent when clipped April 19, 14.4 per cent when cut April 29, and 52 per cent when cut May 9.

SOIL

Relief through the handling of the soil is most difficult because it involves a reduction in available nutrients, particularly nitrates and moisture, for, as was shown in Table 34, those on rich soil may run relatively high in some seasons. Lodging, however, is affected by certain cultural practices to which attention will now be directed.

Fertilizers.—On land in a high state of fertility which is regularly and systematically fertilized, not much, if any, relief from lodging may be expected from the use of any particular kind or combination of fertilizers, but the point in the rotation at which the fertilizer is applied may make a marked difference as illustrated in Figure 39.

Fig. 39.—Both plots are a part of the same rotation—corn, oats, wheat, and clover—and both receive the same kind and quantity of fertilizer but one (left) when the land is in clover; the other when it is in wheat.

Although the application made on the clover did not induce lodging, it proved to be the most unprofitable point in the rotation at which to apply the fertilizer. The 15-year average increase obtained from the application at different points in the rotation of 500 pounds per acre per rotation of a 4-16-4 is shown in Table 46.

Straw mulch.—The use of a straw mulch tends to inhibit the development of nitrates and hence to prevent lodging. Straw may be used to advantage in a rotation like potatoes, wheat, and clover, the straw being used to mulch the potatoes. In 1925 potatoes were mulched at the rate of 10 tons per acre, and in 1926 they were mulched at different rates—4, 6, 8, and 10 tons per acre. The effect of the straw is shown in Table 47 for 1925 and in Table 48 for 1926. In both years it resulted in a decrease in nitrates and an increase in moisture. The reduction of nitrates in 1925 was still apparent in 1926, for the wheat grown on the mulched plots was decidedly lighter green in color, the difference being very distinct and noticeable at a considerable distance. The yield of wheat was reduced 8.1 bushels, the average of the unmulched plots being 44.1 bushels per acre and that of the mulched, 36.0 bushels. The yield of wheat following unmulched and mulched potatoes was 29.4 and 20.7 bushels, respectively, in 1927, and 32.1 and 22.6 bushels, respectively, in 1929. In some seasons the reduction in yield of wheat would be more than offset by an increase in yield of potatoes, for in 1925, a dry season, the mulch practically doubled the yield of potatoes. In these tests the straw was removed, as far as possible, before sowing the wheat.

TABLE 46.—Fertilizers Applied to Different Crops in the Rotation

Crops receiving fertilizer	15-year average increase				Value of increase per rotation	Cost of fertilizer	Balance per rotation
	Corn	Oats	Wheat	Clover			
	Bu.	*Bu.*	*Bu.*	*Lb.*	*Dol.*	*Dol.*	*Dol.*
All four crops equally	11.03	8.57	11.38	984	30.85	12.95	17.90
Corn, oats, and wheat	13.45	9.21	14.32	697	35.16	12.95	22.21
Corn and wheat	12.64	5.69	14.97	726	34.10	12.95	21.15
Corn	15.58	8.46	8.51	432	27.87	12.95	14.92
Wheat	7.38	2.98	17.42	1192	34.47	12.95	21.52
Clover	11.57	3.81	6.71	1546	26.32	12.95	13.37

TABLE 47.—Straw Mulch, Applied to Potatoes, in Relation to Nitrates and Moisture—1925

Date	Nitrates				Moisture			
	10 T.	Check	10 T.	Check	10 T.	Check	10 T.	Check
	ppm.	*ppm.*	*ppm.*	*ppm.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
June 2	22.3	28.1	19.2	30.1	16.5	12.1	16.4	13.3
June 12	30.2	43.7	31.5	33.8	19.5	10.8	15.0	12.1
July 6	19.1	43.4	16.9	39.7	19.6	12.6	19.8	14.4
July 16	9.2	17.1	13.3	13.5	18.9	12.3	19.3	12.7
July 27	13.3	17.7	10.0	14.9	17.0	11.0	17.7	11.2
Aug. 6	1.6	16.2	4.3	14.0	15.5	14.0	18.0	16.6
Aug. 16	2.5	7.3	5.1	5.4	16.9	12.6	16.1	14.0
Aug. 26	8.1	20.4	7.2	11.8	12.2	8.8	20.5	9.3
Sept. 8	1.2	5.7	2.5	4.1	16.9	13.2	16.7	12.7
Sept. 18	8.4	5.9	4.8	8.1	19.0	16.2	18.2	16.4
Sept. 26	9.1	9.8	14.7	8.2	17.9	12.9	17.5	13.5
Oct. 8	13.1	19.2	10.7	5.9	18.4	16.4	19.7	15.7
Oct. 20	4.0	10.9	4.5	6.8	20.9	18.5	20.6	21.4
Nov. 20	10.1	14.5	15.1	13.4	18.9	18.7	19.7	20.4
Average	10.87	18.56	11.41	14.98	17.72	13.58	18.23	14.55

TABLE 48.—Straw Mulch, Applied to Potatoes, in Relation to Nitrates and Moisture—1926

Date	Nitrates						Moisture					
	4 T.	Check	6 T.	8 T.	Check	10 T.	4 T.	Check	6 T.	8 T.	Check	10 T.
July 16	1.9	17.7	9.4	12.0	11.5	8.4	19.0	11.0	18.0	19.0	14.5	20.0
July 25	2.3	22.0	9.3	7.0	13.2	8.1	17.0	10.5	16.0	16.2	10.5	19.0
Aug. 1	13.2	19.3	8.3	6.8	23.2	5.3	12.0	8.5	12.5	13.0	10.0	15.0
Aug. 8	6.0	8.8	4.7	6.0	11.7	7.1	16.5	11.0	15.5	15.5	9.8	16.5
Aug. 18	6.0	14.2	4.7	4.8	6.9	2.4	16.5	16.0	15.6	18.0	14.0	18.5
Aug. 26	2.3	6.4	5.8	5.1	8.4	6.6	15.8	11.5	15.5	15.3	11.0	16.3
Sept. 21	3.3	7.4	7.3	6.7	8.0	5.0	19.5	20.0	19.5	17.5	21.5	21.0
Oct. 7	3.9	4.9	3.4	4.9	5.1	4.9	20.0	20.5	20.0	20.5	22.5	20.5
Average	4.86	12.59	6.61	6.66	11.00	5.98	17.03	13.62	16.60	16.88	14.22	18.35

Rotations.—A rotation so planned that two or more years preceding the small grain crop are devoted to high nitrogen-requiring crops (rotations like corn, corn, wheat, clover or corn, soybeans, corn, wheat, clover) will prove helpful. On the other hand, several years devoted to the growing of a legume in a rotation such as corn, oats, alfalfa, alfalfa, alfalfa makes for lodging as is shown in Figure 30.

Preparation of seedbed.—Disking instead of plowing for oats may make the difference between lodging and non-lodging in some seasons. No preparation of the seedbed, and this is not an uncommon practice in some sections of the State, is even more effective than disking. The difference between no preparation and plowing is illustrated in Figure 31.

SUMMARY

1. Lodging in oats and wheat, as used in this publication, refers to grain which has partly or completely fallen over as a result of factors other than mechanical impact, such as violent wind, rain, or hail storms.

2. The falling over may or may not be accompanied by an abrupt bend in the stems. The bend, if any, usually occurs near one of the lower nodes, below the node if lodging takes place early in the season while the leaf sheaths are still enveloping the stems closely, and above the node if lodging develops after the sheaths have withered and become loose around the stems. In each internode the zone immediately above the node is smallest in diameter and during the period of development is usually highest in moisture content.

3. Lodging is due to the interaction of many factors, both environmental, including soil and climate, and hereditary. Whenever the interaction of these factors results in the development of a relatively low content of dry matter per unit length of culm, lodging occurs.

4. Low dry matter per unit length of culm results from the development of stems relatively small in diameter in proportion to their length. Such stems may result either indirectly through a setting up within the plant of a low carbohydrate-nitrogen relation or directly from a thick stand.

5. A low carbohydrate-nitrogen relation results from such factors as hypernutrition, shading, and relatively high temperature, and it is accompanied by a relatively high proportion of vegetative or straw growth. See Tables 1, 2, 3, and 4.

6. A thick stand may result directly from a thick seeding of normal-sized seeds, from a normal rate of seeding of small-sized seeds, from a normal rate of seeding of a prolifically tillering variety, or from a combination of two or more of these factors.

7. A thick stand on rich ground may result indirectly from the use of normal-sized seeds sown at the normal rate through relatively prolific tillering. In such a situation the reduction in dry matter per unit length of culm is due to the development of stems not only relatively small in diameter but relatively low in percentage composition of dry matter, the latter resulting not only from the relatively high nitrate content of the plant but also from the fact that in a thick stand the degree of shading is greater than in a thin stand.

8. On rich ground, to which lodging is chiefly confined, the chain of sequence appears to be hypernutrition, low carbohydrate-nitrogen relation, a preponderance of vegetative growth, and straw weakness. On poor soil, the reverse is true: a high carbohydrate-nitrogen relation, a reduction in proportion of vegetative growth, and straw strength.

9. In general, both the zone of hypodermal tissue and the cell walls were thicker in high carbohydrate-nitrogen relation plants than in the low carbohydrate-nitrogen relation plants, also in the thin seeding as contrasted with the thick seeding.

10. Lodging is confined principally to rich land, and, on account of climatic variations from year to year, it is more prevalent in some seasons than others, being most common in warm, rainy, cloudy seasons.

11. Relief from lodging so far as the situation is amenable to control may be obtained in part through the seed used and in part through the handling of the soil.

12. In rate-of-seeding tests, plants from the thicker rates often lodge while those from the thinner ones remain erect, Figure 24.

13. In size-of-seed tests, the difference being such as can be obtained by passing the grain repeatedly through a good fanning mill, the plants grown from the small seeds often lodge while those grown from the large seeds remain erect. See Figure 25.

14. Among varieties there is much difference in stiffness of straw. The stiff-strawed varieties usually tiller sparingly and, consequently, establish a relatively thin stand of comparatively strong, coarse culms. See Figure 26.

15. Clipping tends to reduce the number and height of culms and hence to militate against lodging, but it is not a highly success-

ful practice for so much depends on the character of the subsequent season that it is impossible to determine the most appropriate time at which to make the clipping.

16. So far as the soil is concerned, some relief may be obtained through observance of the point in the rotation at which the fertilizer is applied. See Figure 39. The most helpful practices, however, are those which tend to reduce temporarily the available fertility, particularly the nitrates.

17. A straw mulch tends to reduce the nitrate content of the soil, and it can be used in a practical way where potatoes are grown under straw and in such a rotation as potatoes, wheat, and clover.

18. A rotation in which the small grain crop is preceded by gross feeding crops like corn and soybeans is preferable to one in which a legume like alfalfa predominates. See Figure 30.

19. Plowing rather than disking or no preparation of seedbed often results in an increase of soil nitrates and frequently makes the difference between lodging and non-lodging. See Figure 31.

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